Pure & Appl. Chem., Vol. 64, No. 10, pp. 1545–1562, 1992.
Printed in Great Britain.

INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

PHYSICAL CHEMISTRY DIVISION
COMMISSION ON THERMODYNAMICS*

CONVERSION OF TEMPERATURES AND THERMODYNAMIC PROPERTIES TO THE BASIS OF THE INTERNATIONAL TEMPERATURE SCALE OF 1990

(Technical Report)

Prepared for publication by
ROBERT N. GOLDBERG[1] AND RON D. WEIR[2]

[1]National Institute of Standards & Technology, Gaithersburg, Maryland 20899, USA
[2]Department of Chemistry & Chemical Engineering, Royal Military College of Canada, Kingston, Ontario K7K 5LO, Canada

*Membership of the Commission during the preparation of the report (1991–93) is as follows:

Chairman; P. A. G. O'Hare (USA); *Secretary*: G. M. Olofsson (Sweden); *Titular Members*: J. M. G. Barthel (FRG); G. Della Gatta (Italy); M. B. Ewing (UK); M. T. Rätzsch (FRG); W. A. Wakeham (UK); *Associate Members*: T. W. De Loos (Netherlands); J. H. Dymond (UK); R. N. Goldberg (USA); J.-P. E. Grolier (France); I. L. Khodakovsky (Russia); J. L. Laynez (Spain); T. Letcher (Republic of South Africa); C. A. Nieto de Castro (Portugal); S. L. Randzio (Poland); R. D. Weir (Canada); E. Wilhelm (Austria); J. Winkelmann (FRG); *National Representatives*: R. Fernández-Prini (Argentina); C. Airoldi (Brazil); I. Samohýl (Czechoslovakia); F. Rouquérol (France); E. Berecz (Hungary); H. Suga (Japan); R. Karim (Malaysia); P. J. McElroy (New Zealand); F. Grønvold (Norway); M. M. Kopecni (Yugoslavia).

Conversion of temperatures and thermodynamic properties to the basis of the International Temperature Scale of 1990 (Technical Report)

Abstract - Tables of temperature differences between the International Temperature Scale of 1990 (ITS-90) and earlier temperature scales (IPTS-68, EPT-76, IPTS-48, and ITS-27) are presented. These tables also contain values of the derivatives of these differences with respect to temperature. Analytical equations to reproduce the temperature difference (T_{90} - T_{68}) and its first derivative are also given. This information is needed for the adjustment of thermodynamic results to the basis of the ITS-90. Thus, for the most accurate thermodynamic results, it is preferable to change the temperatures of the original work to the ITS-90 and then recalculate the thermodynamic results on this basis. However, conversion formulae based upon a Taylor expansion of the enthalpy have been derived previously by Douglas (*J. Res. Natl. Bur. Stand., Sect. A 73*, 451-470 (1969)). These equations are greatly simplified when the differences between the two temperature scales are small. Approximate effects resulting from the conversion from the IPTS-68 to the ITS-90 and from the IPTS-48 to the ITS-90 for existing calorimetric determinations of heat capacity, enthalpy, and entropy have been calculated with the equations of Douglas for ND_4ReO_4(s), $BaSnF_4$(s), α-Al_2O_3(s), BeO·Al_2O_3(s), BeO·3Al_2O_3(s), and Mo(s). The results of these calculations are given in tables which can be used to assess conveniently the approximate effects on thermodynamic properties due to the differences in these temperature scales. It is found that only the most accurate thermodynamic results require examination and possible adjustment because of a change in the temperature scale.

INTRODUCTION

The International Temperature Scale of 1990 (ITS-90) was adopted by the International Committee of Weights and Measures in 1989 (ref. 1) in accordance with the request in Resolution 7 of the 18th General Conference of Weights and Measures of 1987. This temperature scale supersedes the International Practical Temperature Scale of 1968 as amended in 1975 (IPTS-68) and the 1976 Provisional 0.5 K to 30 K Temperature Scale (EPT-76). Recent reviews (ref. 2-6) of the ITS-90 (T_{90}) have appeared which describe how the scale is operationally defined for temperatures greater than 0.65 K in terms of vapor-pressure thermometry, gas thermometry, platinum resistance thermometry, and optical pyrometry. These reviews also present numerical and graphical comparisons between the ITS-90 and the IPTS-68 (T_{68}) and numerical comparisons with EPT-76. In particular, the Working Group of the Comité Consultatif de Thermométrie has also prepared a monograph "Techniques for Approximating the International Temperature Scale of 1990" (ref. 5) which contains a discussion of the techniques used to establish and use the ITS-90. The officially established tables of differences between the ITS-90 and the EPT-76 and the IPTS-68 are given in reference 1 and are also given in references 2-6. The range of differences encountered over several temperature intervals are: -9 mK to +14 mK over the interval 15 K to 310 K; zero to -124 mK over the interval 310 K to 930 K; and -2.58 K to +0.36 K over the interval 930 K to 4300 K. However, it should be noted that these differences are given to an imprecision that is less than the realizable accuracy of the IPTS-68. The temperature scales preceding the most recent ones (IPTS-68, EPT-76, and ITS-90) are the IPTS-48 (also known as ITS-48), the ITS-27, and the Normal Hydrogen Scale (NHS). The latter scale was established in 1887 (ref. 7). Reference 7 contains tables giving numerical values of the approximate differences (t_{27} - t_{48})/°C as a function of t_{27}/°C and (t_{68} - t_{48})/°C as a function of t_{68}/°C.

The main effects of the ITS-90 on the field of thermodynamics are twofold. Firstly, for the most accurate work, temperatures measured with thermometers that are not recalibrated to the ITS-90 must be converted to the new scale. Secondly, thermodynamic quantities already published in the literature and based on previous temperature scales will be changed in relation to the ITS-90. The methods for making these changes and their magnitudes need to be set out. For very many cases it is found that these corrections are much smaller than the uncertainties in the measurements and therefore can be neglected. The present article addresses these items in order to assist the thermodynamics community affected by the change in the temperature scale. Accordingly, we have: (1) constructed tables which permit one to adjust temperatures reported on the earlier temperature scales to the ITS-90; (2) summarized procedures that can be used to make the necessary adjustments in thermodynamic results; and (3) given results of some calculations of the approximate effects on thermodynamic properties due to the change from the IPTS-48 and IPTS-68 to the ITS-90.

DIFFERENCES BETWEEN THE ITS-90 AND EARLIER TEMPERATURE SCALES

The officially recommended differences between the ITS-90 and the EPT-76 and between the ITS-90 and the IPTS-68 are given in Table VI of reference 1. This table contain the differences $(T_{90} - T_{76})/\mathrm{K}$ and $(T_{90} - T_{68})/\mathrm{K}$ as functions of T_{90}/K and $(t_{90} - t_{68})/°\mathrm{C}$ as a function of $t_{90}/°\mathrm{C}$. However, what is generally needed for the adjustment of results reported on earlier temperature scales is a table of differences as a function of the temperature on that earlier scale. Thus, Table 1 ($t_{68}/°\mathrm{C}$ = -180 to 4000) and Table 2 (T_{68}/K = 14 to 4300) in this paper have been constructed from Table VI in reference 1. In these tables the differences in the two scales are given as the quantity δ equal to either $(t_{90} - t_{68})/°\mathrm{C}$ or $(T_{90} - T_{68})/\mathrm{K}$ as a function of, respectively, $t_{68}/°\mathrm{C}$ or T_{68}/K.† These tables also contain values of the derivatives of the differences $\{d\delta/d(T/\mathrm{K})\}$ as a function of the temperature of the earlier scale. These derivatives were calculated numerically for temperatures less than 1337.15 K (1064 °C). Here we have used the E01BEF subroutine in the NAG Library (ref. 8) to obtain a piecewise monotone cubic Hermite interpolant to the temperature differences. The derivatives are also calculated with this subroutine. Mathematical subroutines that will accomplish these types of operations are generally available (ref. 9). For temperatures higher than 1337.15 K, we used an exact equation (eq. (10) below) to obtain the derivatives. These derivatives will be needed later for the adjustment of thermodynamic properties from the IPTS-68 to the IPTS-90. Also note that there is a discontinuity in the derivative $d\delta/d(T/\mathrm{K})$ at $t_{90}/°\mathrm{C}$ = 630.6 or T_{90}/K = 903.75. In a similar manner, Table 3, which contains the differences $\delta = (T_{90} - T_{76})/\mathrm{K}$ and derivatives of these differences $d\delta/d(T/\mathrm{K})$ as a function of T_{76}/K, was constructed from Table 6 in reference 2 and Appendix A in reference 5.

Table 1.III in reference 7 contains approximate differences $(t_{68} - t_{48})/\mathrm{K}$ as a function of $t_{68}/°\mathrm{C}$ from $t_{68}/°\mathrm{C}$ = -100 to 4000. We have used these differences and Tables 1 and 2 in this paper to construct Table 4. This table gives the differences $\delta = (t_{90} - t_{48})/°\mathrm{C}$ and the derivatives of these differences $d\delta/d(T/\mathrm{K})$ as a function of $t_{48}/°\mathrm{C}$. Similarly, from Table 1.II in reference 7, which gives approximate differences $(t_{27} - t_{48})/\mathrm{K}$ as a function of $t_{27}/°\mathrm{C}$, and with Tables 1, 2, and 4 in this paper, we have constructed Table 5. This table contains the approximate differences $\delta = (t_{90} - t_{27})/°\mathrm{C}$ and derivatives of these differences $d\delta/d(T/\mathrm{K})$ as a function of $t_{27}/°\mathrm{C}$. For $t_{27}/°\mathrm{C} < 630$, the same values given in Table 4 for $t_{48}/°\mathrm{C}$ should be used since the definition of the ITS-27 and the IPTS-48 are identical below that temperature (ref. 7). Although not an internationally recognized temperature scale, the National Bureau of Standards realized and maintained a scale of its own (NBS-55) for the temperature interval 13 K to 90 K from 1955 until the establishment of the IPTS-68. A table of the differences $(T_{68} - T_{\mathrm{NBS\text{-}55}})$ as a function of $T_{\mathrm{NBS\text{-}55}}$ is given in Appendix C in reference 10.

†A second-order correction to the differences is needed due to the shift in the independent variable from T_{90}/K (or $t_{90}/°\mathrm{C}$) to T_{68}/K (or $t_{68}/°\mathrm{C}$). However, this second-order correction was found in all cases to be less than the least significant figure given for the differences between the two temperature scales. A point related to the construction of all of the tables and equations given in this paper pertains to the notation used for temperature. When it is necessary to specify the temperature scale, it is current practice to attach a subscript to the thermodynamic temperature (T) and to the Celsius temperature (t). Thus, the temperature on the ITS-90 is expressed as T_{90} or t_{90}. The kelvin is kept fixed at exactly 1/273.16 of the thermodynamic temperature of the triple point of water. The Celsius temperature is defined by: $t/°\mathrm{C} = T/\mathrm{K} - 273.15$.

The Normal Hydrogen Scale (NHS) was adopted in 1887 by the Comité International des Poids et Mesures. This scale had been developed by Chappuis and was based on gas thermometry measurements with the ice and steam points fixed at 0 °C and 100 °C, respectively. The initial range of this scale was -25 °C to 100 °C but was gradually extended (ref. 7). If it is assumed that there were no errors in the determination of the ice and steam points and that the scale is linear over its entire range, the following relationships are obtained:

$$\delta = (t_{90} - t_{\mathrm{NHS}})/°\mathrm{C} = -0.00026(t_{\mathrm{NHS}}/°\mathrm{C}) \tag{1}$$

$$d\delta/d(T/K) = -0.00026. \tag{2}$$

To summarize, Tables 1-5 can be used to locate conveniently both the appropriate differences and the derivatives of these differences for the conversions from the ITS-27, the IPTS-48, the IPTS-68, and the EPT-76 to the ITS-90. Equations 1 and 2 can be used to accomplish any necessary conversions from the NHS to the ITS-90. Note that on the ITS-27, $T_{27}/\mathrm{K} = t_{27}/°\mathrm{C} + 273.00$. On the IPTS-48, the IPTS-68, and the ITS-90, $T/\mathrm{K} = t/°\mathrm{C} + 273.15$. Users of results published during the period *circa* 1945-1955 should pay particular attention as to how $t/°\mathrm{C}$ was converted to T/K since, in many cases, the constant 273.16 was used instead of 273.15. The differences between the earlier temperature scales and ITS-90 are shown in figures 1 and 2.

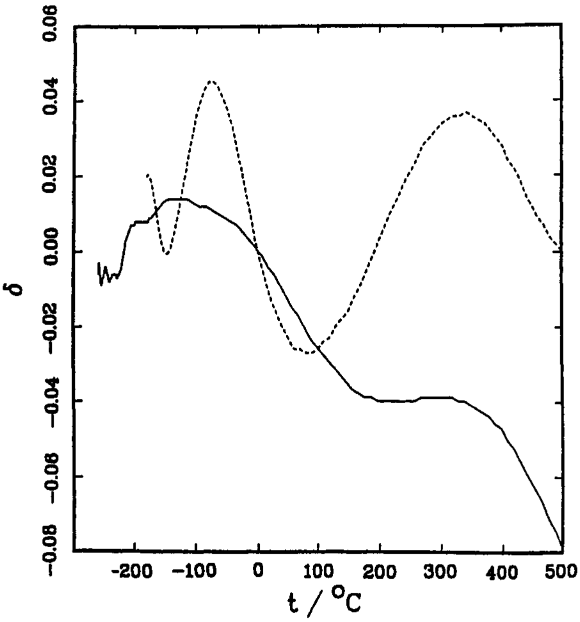

Fig. 1. The quantity $\delta = (T_{90} - T_x)/\mathrm{K}$ as a function of $t/°\mathrm{C}$. The two curves are: solid line, x = 68; dashed line, x = 48 and x = 27.

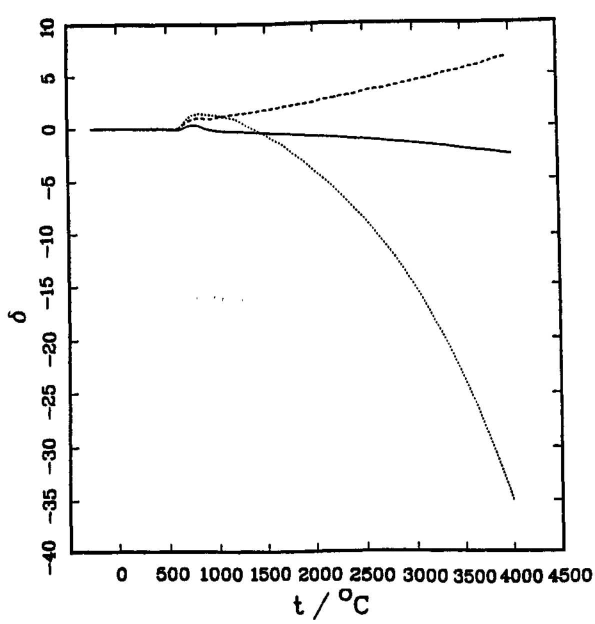

Fig. 2. The quantity $\delta = (T_{90} - T_x)/\mathrm{K}$ as a function of $t/°\mathrm{C}$. The three curves are: solid line, x = 68; dashed line, x = 48; and dotted line, x = 27.

ANALYTICAL EQUATIONS FOR THE CONVERSION OF T_{68} TO T_{90}

Analytical equations for the differences between the ITS-90 and the IPTS-68 are also useful. They have been worked out by R.L. Rusby and have been adopted by the Comité Consultatif de Thermométrie of the Comité International des Poids et Mesures (ref. 4). The coefficients of these equations, which are now summarized, are given in Table 6.

The following polynomial represents $(T_{90} - T_{68})/\mathrm{K}$ from $T_{90}/\mathrm{K} = 13.8$ to 73.15 with an accuracy of about 0.001 K:

$$(T_{90} - T_{68})/K = a_o + \sum_{i=1}^{12} a_i[\{(T_{90}/K) - 40\}/40]^i. \tag{3}$$

The first derivative $\mathrm{d}(T_{90} - T_{68})/\mathrm{d}T_{90}$ is also required for the calculation of changes to some of the thermodynamic quantities caused by the shift in the temperature scale. This derivative is:

$$d(T_{90} - T_{68})/dT_{90} = (1/40)\sum_{i=1}^{12} ia_i[\{(T_{90}/K) - 40\}/40]^{i-1}. \tag{4}$$

From 83.8 K to 903.75 K (-189.35 °C to 630.6 °C), $(T_{90} - T_{68})$/K is reproduced by the following equation:

$$(T_{90} - T_{68})/K = \sum_{i=1}^{8} b_i[\{(T_{90}/K) - 273.15\}/630]^{i}. \tag{5}$$

The accuracy of the above equation is 0.0015 K from 83.8 K to 273.15 K and 0.001 K from 273.15 K to 903.75 K. The derivative $d(T_{90} - T_{68})/dT_{90}$ in the temperature interval 83.8 K to 903.75 K is:

$$d(T_{90} - T_{68})/dT_{90} = (1/630)\sum_{i=1}^{8} ib_i[\{(T_{90}/K) - 273.15\}/630]^{i-1}. \tag{6}$$

It should be noted that a discontinuity in the first derivative of $(T_{90} - T_{68})$ with respect to T_{90} occurs at 903.75 K (630.6 °C).

For the interval 903.75 K to 1337.33 K (630.6 °C to 1064.18 °C), $(T_{90} - T_{68})$/K is reproduced to within about 0.01 K by:

$$(T_{90} - T_{68})/K = c_0 + \sum_{i=1}^{7} c_i[\{(T_{90}/K) - 1173.15\}/300]^{i}. \tag{7}$$

The first derivative in this temperature interval is:

$$d(T_{90} - T_{68})/dT_{90} = (1/300)\sum_{i=1}^{7} ic_i[\{(T_{90}/K) - 1173.15\}/300]^{i-1}. \tag{8}$$

Above 1337.33 K (1064.18 °C), an operational equation for $(T_{90} - T_{68})$/K is:

$$(T_{90} - T_{68})/K = (T_{90}^2/K)[\{T_{90}(Au) - T_{68}(Au)\}/\{T_{90}(Au)T_{68}(Au)\}] \tag{9}$$

where the freezing temperature of gold T_{90}(Au) = 1337.33 K and T_{68}(Au) = 1337.58 K. Thus, the term in square brackets is a constant equal to -1.398×10^{-7}. This equation is a simpler and essentially equivalent form of eq. (1.5) in reference 4. The silver, gold, and copper freezing temperatures can all be used in the construction of a pyrometric scale. The derivative obtained from the above equation is:

$$d(T_{90} - T_{68})/dT_{90} = 2T_{90}[\{T_{90}(Au) - T_{68}(Au)\}/\{T_{90}(Au)T_{68}(Au)\}]. \tag{10}$$

Eqs. (5) and (7) above have been changed, respectively, from eqs. (1.3) and (1.4) in Table 1.6 in reference 4 to use temperature in kelvins rather than Celsius.

Rusby has recently (ref. 11) modified the above equations so as to give directly $(T_{90} - T_{68})$ from T_{68}. The temperature intervals over which Rusby's modified equations are valid are also slightly different: 13.81 K to 83.8 K for eq. (3); 73.15 K to 903.89 K for eq. (5); and 903.89 K to 1337.58 K for eq. (7). The derivatives which are calculated with the above equations are in reasonable agreement with those which are directly calculated with a Hermite interpolant from the officially (ref. 1) established differences $(T_{90} - T_{68})$/K. However, the derivatives calculated from the above equations are smoother than those obtained from the Hermite interpolant. As is shown below, the effects on thermodynamic properties due to the change from IPTS-68 to the ITS-90 are almost always within the experimental errors of the property measurements. Thus, it is highly unlikely that the uncertainties in the derivatives $d(T_{90} - T_{68})/dT_{90}$ will have a substantive effect on the calculated adjustments. If, however, the actual property measurements should be of exceptional accuracy, it is recommended that such results be recalculated with a point to point conversion of each temperature to the ITS-90.

CONVERSION OF THERMODYNAMIC QUANTITIES

For the most accurate thermodynamic results, it is preferable to change the temperature of the original work to T_{90} as outlined above and then convert the thermodynamic quantities to this basis. However, equations for correcting thermodynamic quantities directly due to the shift in temperature scale have been derived by Douglas (ref. 12). Taylor expansions of the enthalpy H, heat capacity C_p, and entropy S result in exact equations in infinite series from which the corrections δH, δC_p, or δS are determined. The differences between the temperatures of the ITS-90 and the IPTS-68 are sufficiently small to justify dropping higher order terms in these infinite series to produce simpler but approximate equations with sufficient accuracy for nearly all cases, one exception being in the region of sharp transitions. The simplified equations for the changes in the enthalpy, heat capacity, and entropy are, respectively:

$$\delta H = -(T_{90} - T_x)C_p, \tag{11}$$

$$\delta C_p = -(T_{90} - T_x)dC_p/dT - C_p d(T_{90} - T_x)/dT, \tag{12}$$

$$\delta S = -\int_0^T \{(T_{90} - T_x)C_p/T^2\}dT - (T_{90} - T_x)C_p/T. \tag{13}$$

Here, T_x is the thermodynamic temperature on any of the earlier scales (NHS, ITS-27, IPTS-48, IPTS-68, or EPT-76). Eqs. (11), (12), and (13) correspond, respectively, to eqs. (52), (53), and (56) of reference 12. All properties are those at the nominal value of T_{90} where the corrected property is desired. Errors in the differences in calculated thermodynamic properties (e.g. $C_p(90)$ - $C_p(68)$) may also arise from uncertainties in the various terms (particularly dC_p/dT and $d(T_{90} - T_x)/dT$ which are used in eq. (12). Also, we have sometimes used previously fitted results to obtain the approximate differences in thermodynamic properties given in Table 7. We note that the fitting process tends to produce smooth results and, in doing this, it tends to minimize the effects of errors in the measurements, including any errors in the thermometry and in the temperature scale used in the study. *Thus, if one wishes to obtain accurate values of the thermodynamic properties on the ITS-90, it is preferable to correct the original results to ITS-90 and then to perform the desired fit to the results rather than to use the Douglas equations to adjust results which have already been fit.* Therefore, while the differences in thermodynamic properties obtained with the Douglas equations are satisfactory for the purpose of assessing the approximate effects on thermodynamic properties due to differences in temperature scales, the fitted results of a study based upon an earlier temperature scale may have already smoothed out some of the experimental detail in the original measurements. Thus, while exact results will not be obtained with eqs. (11), (12), and (13), they should suffice for the calculation of approximate differences in thermodynamic properties.

Accordingly, we have used eqs. (11), (12), and (13) to assess the effects of the changes from the ITS-68 to the ITS-90 on the thermodynamic properties for six materials which were selected to cover a wide range of temperature. These materials include the heat-capacity studies on ND_4ReO_4(s) by adiabatic calorimetry (ref. 13), $BaSnF_4$ by both adiabatic calorimetry and differential scanning calorimetry (ref. 14, 15), α-Al_2O_3(s) (ref. 16, 17, 18), $BeO{\cdot}Al_2O_3$(s) (ref. 19, 20), and $BeO{\cdot}3Al_2O_3$(s) (ref. 21, 22) by adiabatic and drop-calorimetry, and Mo(s) by adiabatic, drop, and pulse-heating calorimetry (ref. 23, 24). The results of these calculations are given in Table 7 for the change from IPTS-68 to ITS-90 and in Table 8 for the change from IPTS-48 to ITS-90. The predominant contribution made by the term $C_p\mathrm{d}(T_{90} - T_x)/\mathrm{d}T$ in eq. (12) leads one to predict that the effects on $10^2\{C_p(90) - C_p(68)\}/C_p(90)$ are the greatest at temperatures between 16 K and 18 K and at temperatures between 903.75 K and 1320 K. For this reason results are given in Tables 7 and 8 at appropriately spaced temperature intervals. Thus, these two tables can be used to assess the approximate effects on thermodynamic properties due to the changes in these temperature scales (IPTS-48 and IPTS-68) to ITS-90. If the *inaccuracies* in the results are judged to be less than the approximate effects given in Table 7 (or Table 8), then a recalculation of the original results is clearly justified. In some cases the *imprecisions* in the results used to construct Tables 7 and 8 are less than the approximate differences given for the temperature interval 903.75 K to 1320 K (Table 7 and Table 8) and for the temperature interval 100 K to 400 K (Table 8). Indeed, some investigators have noted that problems in the temperature scale could account for some of the deviations in their results. For example, Ditmars and Douglas (ref. 18) found that the fit of their experimental results was not smooth in the interval T = 873 K to T = 1023 K. They wrote (ref. 18) that the "more likely contributing causes to the nonsmoothness (in both the present and the 1956 NBS enthalpy data for α-Al_2O_3) are possible systematic error in the realization of the International Practical Temperature Scale of 1968 in these measurements and especially the differences between this scale and the true thermodynamic one." Similarly, Furukawa and Reilly (ref. 25, 26) were able to detect "anomalies" in the heat capacities of several substances in the region of the oxygen point where the temperature scale (IPTS-48) was based on the joining of the results obtained from platinum resistance and thermocouple thermometers. These anomalies were readily removed after the temperature scale had been properly adjusted. Ginnings states (ref. 27) that "in the range 0-100 °C, the specific heat of liquid water is believed to be known within 0.01-0.02 per cent". Thus, the results of Osborne et al. (ref. 28) on the heat capacity of water should be examined in light of the changes in the temperature scale. The results of Ditmars and Douglas (ref. 18, 20, 22), those of Furukawa and Saba (ref. 19, 21), those of Chang (17), and those of Osborne et al. (ref. 28) have a precision greater than the vast majority of thermodynamic measurements in the literature. Thus, only results which are judged to have inaccuracies less than those effects which are calculated with eqs. (11), (12), or (13) above require examination and possible adjustment because of the change(s) in the temperature scale. Thermodynamic properties which are calculated from statistical mechanics are implicitly done with thermodynamic temperatures. Therefore, no adjustments of the types discussed in this paper are required in this case.

ADDENDUM

Eight laboratories working under the auspices of Working Group 2 of the Comité Consultatif de Thermométrie have recently determined (ref. 29, 30, 31) the differences $\delta = (t_{90} - t_{68})/°\mathrm{C}$ from 630 °C to 1064 °C with temperatures on the International Temperature Scale of 1990 determined with platinum resistance thermometers. These results give a set of temperature differences which differ from the earlier results (see ref. 1 and Tables 1 and 2 in this paper) by as much as 0.32 K over this temperature interval. Burns et al. (ref. 30) have represented these new differences in terms of the following polynomial:

$$\delta = 7.8687209\times10^{1} - 4.7135991\times10^{-1}(t_{90}/°\mathrm{C}) + 1.0954715\times10^{-3}(t_{90}/°\mathrm{C})^2$$
$$-1.2357884\times10^{-6}(t_{90}/°\mathrm{C})^3 + 6.7736583\times10^{-10}(t_{90}/°\mathrm{C})^4 - 1.4458081\times10^{-13}(t_{90}/°\mathrm{C})^5. \quad (14)$$

From 680 °C to 880 °C (T = 953.15 K to T = 1153.15 K) the absolute values of these new temperature differences and the absolute values of the temperature derivatives of these differences are substantially less than the corresponding quantities given in Tables 1 and 2. Thus, the approximate differences in thermodynamic properties calculated with these new temperature differences and the new temperature derivatives of these differences will be substantially less for the temperature interval 953 K to 1153 K than the approximate differences given in Tables 7 and 8.

TABLE 1. Differences $\delta = (t_{90} - t_{68})/°C$ and derivatives of these differences $d\delta/d(T/K)$ as a function of $t_{68}/°C$.

$t_{68}/°C$	δ	$d\delta/d(T/K)$	$t_{68}/°C$	δ	$d\delta/d(T/K)$	$t_{68}/°C$	δ	$d\delta/d(T/K)$
-180	0.008	0.00020	400	-0.048	-0.00024	980	-0.17	-0.0010
-170	0.010	0.00020	410	-0.051	-0.00024	990	-0.18	-0.0010
-160	0.012	0.00013	420	-0.053	-0.00024	1000	-0.19	-0.0010
-150	0.013	0.00010	430	-0.056	-0.00030	1010	-0.20	-0.0010
-140	0.014	0.00000	440	-0.059	-0.00030	1020	-0.21	-0.0010
-130	0.014	0.00000	450	-0.062	-0.00030	1030	-0.22	-0.0010
-120	0.014	0.00000	460	-0.065	-0.00030	1040	-0.23	-0.0010
-110	0.013	0.00000	470	-0.068	-0.00034	1050	-0.24	-0.0010
-100	0.013	0.00000	480	-0.072	-0.00034	1060	-0.25	0.0000
-90	0.012	0.00000	490	-0.075	-0.00034	1070	-0.25	-0.00038
-80	0.012	0.00000	500	-0.079	-0.00040	1100	-0.26	0.00038
-70	0.011	-0.00010	510	-0.083	-0.00040	1200	-0.30	-0.00041
-60	0.010	-0.00010	520	-0.087	-0.00034	1300	-0.35	-0.00044
-50	0.009	-0.00010	530	-0.090	-0.00034	1400	-0.39	-0.00047
-40	0.008	-0.00013	540	-0.094	-0.00040	1500	-0.44	-0.00050
-30	0.006	-0.00020	550	-0.098	-0.00034	1600	-0.49	-0.00052
-20	0.004	-0.00020	560	-0.101	-0.00034	1700	-0.54	-0.00055
-10	0.002	-0.00020	570	-0.105	-0.00034	1800	-0.60	-0.00058
0	0.000	-0.00020	580	-0.108	-0.00034	1900	-0.66	-0.00061
10	-0.002	-0.00024	590	-0.112	-0.00034	2000	-0.72	-0.00064
20	-0.005	-0.00024	600	-0.115	-0.00030	2100	-0.79	-0.00066
30	-0.007	-0.00024	610	-0.118	-0.00034	2200	-0.85	-0.00069
40	-0.010	-0.00030	620	-0.122	-0.00034	2300	-0.93	-0.00072
50	-0.013	-0.00030	630	-0.125	0.00000	2400	-1.00	-0.00075
60	-0.016	-0.00024	640	-0.08	0.0049	2500	-1.07	-0.00078
70	-0.018	-0.00024	650	-0.03	0.0050	2600	-1.15	-0.00080
80	-0.021	-0.00030	660	0.02	0.0044	2700	-1.24	-0.00083
90	-0.024	-0.00024	670	0.06	0.0044	2800	-1.32	-0.00086
100	-0.026	-0.00020	680	0.11	0.0050	2900	-1.41	-0.00089
110	-0.028	-0.00020	690	0.16	0.0044	3000	-1.50	-0.00091
120	-0.030	-0.00020	700	0.20	0.0040	3100	-1.59	-0.00094
130	-0.032	-0.00020	710	0.24	0.0040	3200	-1.69	-0.00097
140	-0.034	-0.00020	720	0.28	0.0034	3300	-1.78	-0.00100
150	-0.036	-0.00013	730	0.31	0.0024	3400	-1.89	-0.00103
160	-0.037	-0.00010	740	0.33	0.0020	3500	-1.99	-0.00105
170	-0.038	-0.00010	750	0.35	0.0013	3600	-2.10	-0.00108
180	-0.039	0.00000	760	0.36	0.0000	3700	-2.21	-0.00111
190	-0.039	0.00000	770	0.36	0.0000	3800	-2.32	-0.00114
200	-0.040	0.00000	780	0.36	0.0000	3900	-2.43	-0.00117
210	-0.040	0.00000	790	0.35	-0.0010	4000	-2.55	-0.00119
220	-0.040	0.00000	800	0.34	-0.0013			
230	-0.040	0.00000	810	0.32	-0.0024			
240	-0.040	0.00000	820	0.29	-0.0034			
250	-0.040	0.00000	830	0.25	-0.0034			
260	-0.040	0.00000	840	0.22	-0.0034			
270	-0.039	0.00000	850	0.18	-0.0040			
280	-0.039	0.00000	860	0.14	-0.0040			
290	-0.039	0.00000	870	0.10	-0.0040			
300	-0.039	0.00000	880	0.06	-0.0034			
310	-0.039	0.00000	890	0.03	-0.0034			
320	-0.039	0.00000	900	-0.01	-0.0027			
330	-0.040	0.00000	910	-0.03	-0.0024			
340	-0.040	0.00000	920	-0.06	-0.0024			
350	-0.041	-0.00010	930	-0.08	-0.0020			
360	-0.042	-0.00010	940	-0.10	-0.0020			
370	-0.043	-0.00013	950	-0.12	-0.0020			
380	-0.045	-0.00013	960	-0.14	-0.0020			
390	-0.046	-0.00013	970	-0.16	-0.0013			

TABLE 2. Differences $\delta = (T_{90} - T_{68})$/K and derivatives of these differences $d\delta/d(T/K)$ as a function of T_{68}/K.

T_{68}/K	δ	$d\delta/d(T/K)$	T_{68}/K	δ	$d\delta/d(T/K)$	T_{68}/K	δ	$d\delta/d(T/K)$
14	-0.006	0.0050	74	0.007	0.0000	430	-0.037	-0.00013
15	-0.003	0.0000	75	0.008	0.0000	440	-0.038	-0.00010
16	-0.004	-0.0013	76	0.008	0.0000	450	-0.039	0.00000
17	-0.006	-0.0020	77	0.008	0.0000	460	-0.039	0.00000
18	-0.008	-0.0013	78	0.008	0.0000	470	-0.040	0.00000
19	-0.009	0.0000	79	0.008	0.0000	480	-0.040	0.00000
20	-0.009	0.0000	80	0.008	0.0000	490	-0.040	0.00000
21	-0.008	0.0010	81	0.008	0.0000	500	-0.040	0.00000
22	-0.007	0.0000	82	0.008	0.0000	510	-0.040	0.00000
23	-0.007	0.0000	83	0.008	0.0000	520	-0.040	0.00000
24	-0.006	0.0010	84	0.008	0.0000	530	-0.040	0.00000
25	-0.005	0.0010	85	0.008	0.0000	540	-0.039	0.00000
26	-0.004	0.0000	86	0.008	0.0000	550	-0.039	0.00000
27	-0.004	0.0000	87	0.008	0.0000	560	-0.039	0.00000
28	-0.005	-0.0010	88	0.008	0.0000	570	-0.039	0.00000
29	-0.006	0.0000	89	0.008	0.0000	580	-0.039	0.00000
30	-0.006	0.0000	90	0.008	0.0000	590	-0.039	0.00000
31	-0.007	-0.0010	91	0.008	0.0000	600	-0.040	0.00000
32	-0.008	0.0000	92	0.008	0.0000	610	-0.040	0.00000
33	-0.008	0.0000	93	0.008	0.0000	620	-0.041	-0.00010
34	-0.008	0.0000	94	0.008	0.0000	630	-0.042	-0.00010
35	-0.007	0.0000	95	0.008	0.0000	640	-0.043	-0.00010
36	-0.007	0.0000	96	0.008	0.0000	650	-0.044	-0.00013
37	-0.007	0.0000	97	0.009	0.0000	660	-0.046	-0.00013
38	-0.006	0.0000	98	0.009	0.0000	670	-0.047	-0.00015
39	-0.006	0.0000	99	0.009	0.0000	680	-0.050	-0.00024
40	-0.006	0.0000	100	0.009	0.0000	690	-0.052	-0.00024
41	-0.006	0.0000	110	0.011	0.00020	700	-0.055	-0.00030
42	-0.006	0.0000	120	0.013	0.00013	710	-0.058	-0.00030
43	-0.006	0.0000	130	0.014	0.00000	720	-0.061	-0.00030
44	-0.006	0.0000	140	0.014	0.00000	730	-0.064	-0.00030
45	-0.007	0.0000	150	0.014	0.00000	740	-0.067	-0.00034
46	-0.007	0.0000	160	0.014	0.00000	750	-0.071	-0.00034
47	-0.007	0.0000	170	0.013	-0.00010	760	-0.074	-0.00034
48	-0.006	0.0000	180	0.012	0.00000	770	-0.078	-0.00040
49	-0.006	0.0000	190	0.012	0.00000	780	-0.082	-0.00040
50	-0.006	0.0000	200	0.011	-0.00010	790	-0.086	-0.00034
51	-0.005	0.0000	210	0.010	-0.00010	800	-0.089	-0.00034
52	-0.005	0.0000	220	0.009	-0.00010	810	-0.093	-0.00040
53	-0.004	0.0010	230	0.008	-0.00010	820	-0.097	-0.00034
54	-0.003	0.0010	240	0.007	-0.00013	830	-0.100	-0.00034
55	-0.002	0.0010	250	0.005	-0.00020	840	-0.104	-0.00034
56	-0.001	0.0010	260	0.003	-0.00020	850	-0.107	-0.00034
57	0.000	0.0010	270	0.001	-0.00026	860	-0.111	-0.00034
58	0.001	0.0010	273.15	0.000	-0.00021	870	-0.114	-0.00030
59	0.002	0.0010	280	-0.001	-0.00019	880	-0.117	-0.00034
60	0.003	0.0000	290	-0.004	-0.00024	890	-0.121	-0.00034
61	0.003	0.0000	300	-0.006	-0.00024	900	-0.124	0.00000
62	0.004	0.0000	310	-0.009	-0.00030	903.75	-0.125	-
63	0.004	0.0000	320	-0.012	-0.00030	910	-0.09	0.0037
64	0.005	0.0000	330	-0.015	-0.00024	920	-0.05	0.0044
65	0.005	0.0000	340	-0.017	-0.00024	930	0.00	0.0050
66	0.006	0.0000	350	-0.020	-0.00030	940	0.05	0.0044
67	0.006	0.0000	360	-0.023	-0.00024	950	0.09	0.0044
68	0.007	0.0000	370	-0.025	-0.00020	960	0.14	0.0050
69	0.007	0.0000	380	-0.027	-0.00020	970	0.19	0.0044
70	0.007	0.0000	390	-0.029	-0.00020	980	0.23	0.0040
71	0.007	0.0000	400	-0.031	-0.00020	990	0.27	0.0034
72	0.007	0.0000	410	-0.033	-0.00020	1000	0.30	0.0024
73	0.007	0.0000	420	-0.035	-0.00020	1010	0.32	0.0020

TABLE 2 (continued)

T_{68}/K	δ	$d\delta/d(T/K)$	T_{68}/K	δ	$d\delta/d(T/K)$	T_{68}/K	δ	$d\delta/d(T/K)$
1020	0.34	0.0020	1300	-0.22	-0.0010	3500	-1.71	-0.00098
1030	0.36	0.0000	1310	-0.23	-0.0010	3600	-1.81	-0.00101
1040	0.36	0.0000	1320	-0.24	-0.0010	3700	-1.92	-0.00103
1050	0.36	0.0000	1330	-0.25	-0.00030	3800	-2.02	-0.00106
1060	0.35	-0.0010	1340	-0.25	-0.00037	3900	-2.13	-0.00109
1070	0.34	-0.0010	1350	-0.26	-0.00038	4000	-2.24	-0.00112
1080	0.33	-0.0015	1360	-0.26	-0.00038	4100	-2.35	-0.00115
1090	0.30	-0.0034	1400	-0.27	-0.00039	4200	-2.46	-0.00117
1100	0.26	-0.0034	1500	-0.31	-0.00042	4300	-2.58	-0.00120
1110	0.23	-0.0034	1600	-0.36	-0.00045			
1120	0.19	-0.0040	1700	-0.40	-0.00048			
1130	0.15	-0.0040	1800	-0.45	-0.00050			
1140	0.11	-0.0040	1900	-0.50	-0.00053			
1150	0.07	-0.0034	2000	-0.56	-0.00056			
1160	0.04	-0.0034	2100	-0.62	-0.00059			
1170	0.00	-0.0027	2200	-0.68	-0.00061			
1180	-0.02	-0.0024	2300	-0.74	-0.00064			
1190	-0.05	-0.0024	2400	-0.81	-0.00067			
1200	-0.07	-0.0020	2500	-0.87	-0.00070			
1210	-0.09	-0.0020	2600	-0.95	-0.00073			
1220	-0.11	-0.0020	2700	-1.02	-0.00075			
1230	-0.13	-0.0020	2800	-1.09	-0.00078			
1240	-0.15	-0.0020	2900	-1.17	-0.00081			
1250	-0.17	-0.0013	3000	-1.26	-0.00084			
1260	-0.18	-0.0010	3100	-1.34	-0.00087			
1270	-0.19	-0.0010	3200	-1.43	-0.00089			
1280	-0.20	-0.0010	3300	-1.52	-0.00092			
1290	-0.21	-0.0010	3400	-1.62	-0.00095			

TABLE 3. Differences $\delta = (T_{90} - T_{76})$/K and derivatives of these differences $d\delta/d(T/K)$ as a function of T_{76}/K.

T_{76}/K	δ	$d\delta/d(T/K)$
5	-0.0001	-0.00010
6	-0.0002	-0.00010
7	-0.0003	-0.00010
8	-0.0004	-0.00010
9	-0.0005	-0.00010
10	-0.0006	-0.00010
11	-0.0007	-0.00010
12	-0.0008	-0.00013
13	-0.0010	-0.00013
14	-0.0011	-0.00013
15	-0.0013	-0.00013
16	-0.0014	-0.00013
17	-0.0016	-0.00020
18	-0.0018	-0.00020
19	-0.0020	-0.00020
20	-0.0022	-0.00024
21	-0.0025	-0.00024
22	-0.0027	-0.00024
23	-0.0030	-0.00024
24	-0.0032	-0.00024
25	-0.0035	-0.00030
26	-0.0038	-0.00030
27	-0.0041	-0.00030

TABLE 4. Approximate differences $\delta = (t_{90} - t_{48})/°C$ and derivatives of these differences $d\delta/d(T/K)$ as a function of $t_{48}/°C$.

$t_{48}/°C$	δ	$d\delta/d(T/K)$	$t_{48}/°C$	δ	$d\delta/d(T/K)$	$t_{48}/°C$	δ	$d\delta/d(T/K)$
-180	0.020	0.00000	400	0.028	-0.00027	980	1.01	0.0020
-170	0.017	-0.00046	410	0.024	-0.00027	990	1.03	0.0020
-160	0.007	-0.00082	420	0.022	-0.00024	1000	1.05	0.0020
-150	0.000	0.00000	430	0.019	-0.00034	1010	1.07	0.0020
-140	0.001	0.00018	440	0.015	-0.00034	1020	1.09	0.0020
-130	0.008	0.00079	450	0.012	-0.00030	1030	1.11	0.0020
-120	0.017	0.00090	460	0.009	-0.00024	1040	1.13	0.0020
-110	0.026	0.00090	470	0.007	-0.00024	1050	1.15	0.0020
-100	0.035	0.00072	480	0.004	-0.00024	1060	1.17	0.0020
-90	0.041	0.00048	490	0.002	-0.00020	1070	1.19	0.0018
-80	0.045	0.00000	500	0.000	-0.00013	1100	1.2	0.0016
-70	0.045	0.00000	510	-0.001	-0.00010	1200	1.4	0.00076
-60	0.042	-0.00034	520	-0.002	0.00000	1300	1.5	0.00076
-50	0.038	-0.00048	530	-0.001	0.00010	1400	1.6	0.0015
-40	0.032	-0.00069	540	0.000	0.00013	1500	1.8	0.0015
-30	0.024	-0.00080	550	0.002	0.00029	1600	1.9	0.0015
-20	0.016	-0.00080	560	0.007	0.00044	1700	2.1	0.0014
-10	0.008	-0.00080	570	0.011	0.00051	1800	2.2	0.0014
0	0.000	-0.00069	580	0.018	0.00070	1900	2.3	0.0014
10	-0.006	-0.00060	590	0.025	0.00082	2000	2.5	0.0017
20	-0.012	-0.00048	600	0.035	0.0011	2100	2.7	0.0017
30	-0.016	-0.00040	610	0.047	0.0012	2200	2.9	0.0017
40	-0.020	-0.00034	620	0.060	0.0014	2300	3.1	0.0016
50	-0.023	-0.00030	630	0.075	0.0025	2400	3.2	0.0017
60	-0.026	0.00000	640	0.15	0.0072	2500	3.4	0.0022
70	-0.026	0.00000	650	0.22	0.0075	2600	3.7	0.0015
80	-0.027	0.00000	660	0.30	0.0075	2700	3.8	0.0015
90	-0.027	0.00000	670	0.37	0.0075	2800	4.0	0.0021
100	-0.026	0.00013	680	0.45	0.0075	2900	4.2	0.0021
110	-0.024	0.00013	690	0.52	0.0070	3000	4.4	0.0021
120	-0.023	0.00015	700	0.59	0.0070	3100	4.6	0.0020
130	-0.020	0.00024	710	0.66	0.0070	3200	4.8	0.0024
140	-0.018	0.00020	720	0.73	0.0058	3300	5.1	0.0024
150	-0.016	0.00027	730	0.78	0.0050	3400	5.3	0.0019
160	-0.012	0.00034	740	0.83	0.0050	3500	5.5	0.0024
170	-0.009	0.00034	750	0.88	0.0044	3600	5.8	0.0023
180	-0.005	0.00040	760	0.92	0.0027	3700	6.0	0.0023
190	-0.001	0.00040	770	0.94	0.0024	3800	6.3	0.0029
200	0.003	0.00040	780	0.97	0.0024	3900	6.6	0.0022
210	0.007	0.00040	790	0.99	0.0020	4000	6.8	0.0013
220	0.011	0.00034	800	1.01	0.0013			
230	0.014	0.00034	810	1.02	0.0000			
240	0.018	0.00034	820	1.01	-0.0010			
250	0.021	0.00030	830	1.00	0.0000			
260	0.024	0.00034	840	1.00	0.0000			
270	0.028	0.00027	850	0.99	-0.0010			
280	0.030	0.00020	860	0.98	-0.0010			
290	0.032	0.00020	870	0.97	-0.0013			
300	0.034	0.00013	880	0.95	0.0000			
310	0.035	0.00010	890	0.95	0.0000			
320	0.036	0.00000	900	0.94	0.0000			
330	0.036	0.00000	910	0.95	0.0000			
340	0.037	0.00000	920	0.95	0.0000			
350	0.036	-0.00010	930	0.96	0.0010			
360	0.035	-0.00010	940	0.97	0.0010			
370	0.034	-0.00013	950	0.98	0.0000			
380	0.032	-0.00020	960	0.98	0.0000			
390	0.030	-0.00020	970	0.99	0.0013			

TABLE 5. Approximate differences $\delta = (t_{90} - t_{27})/°C$ and derivatives of these differences $d\delta/d(T/K)$ as a function of $t_{27}/°C$. For $t_{27}/°C < 630$, the values given in Table 4 for $t_{48}/°C$ should be used.

$t_{27}/°C$	δ	$d\delta/d(T/K)$	$t_{27}/°C$	δ	$d\delta/d(T/K)$
630	0.08	0.012	1000	1.25	0.0000
640	0.19	0.011	1010	1.25	0.0000
650	0.30	0.011	1020	1.24	-0.0013
660	0.42	0.011	1030	1.22	-0.0013
670	0.52	0.010	1040	1.21	-0.0010
680	0.63	0.010	1050	1.20	-0.0013
690	0.73	0.010	1060	1.18	-0.0024
700	0.83	0.010	1100	1.04	-0.0021
710	0.93	0.0095	1200	0.90	-0.0022
720	1.02	0.0079	1300	0.35	-0.0049
730	1.09	0.0070	1400	-0.09	-0.0044
740	1.16	0.0070	1500	-0.54	-0.0050
750	1.23	0.0065	1600	-1.09	-0.0055
760	1.29	0.0040	1700	-1.64	-0.0064
770	1.32	0.0038	1800	-2.40	-0.0071
780	1.37	0.0038	1900	-3.06	-0.0075
790	1.40	0.0024	2000	-3.92	-0.0081
800	1.42	0.0020	2100	-4.69	-0.0081
810	1.44	0.0000	2200	-5.55	-0.0092
820	1.44	0.0000	2300	-6.53	-0.010
830	1.43	0.0000	2400	-7.60	-0.010
840	1.43	0.0000	2500	-8.57	-0.011
850	1.42	-0.0010	2600	-9.75	-0.012
860	1.41	-0.0013	2700	-11.0	-0.012
870	1.39	-0.0024	2800	-12.2	-0.013
880	1.36	0.0000	2900	-13.6	-0.014
890	1.36	0.0000	3000	-15.1	-0.015
900	1.34	-0.0013	3100	-16.6	-0.016
910	1.33	-0.0010	3200	-18.3	-0.016
920	1.32	0.0000	3300	-19.9	-0.017
930	1.32	0.0000	3400	-21.7	-0.019
940	1.31	-0.0010	3500	-23.7	-0.020
950	1.30	-0.0013	3600	-25.7	-0.021
960	1.28	-0.0013	3700	-27.9	-0.022
970	1.27	0.0000	3800	-30.1	-0.023
980	1.27	0.0000	3900	-32.4	-0.025
990	1.26	-0.0010	4000	-35.1	-0.028

TABLE 6. The parameters a_i, b_i, c_i in eqs. (3) to (8).

i	a_i	b_i	c_i
0	-0.005903	0	-0.00317
1	0.008174	-0.148759	-0.97737
2	-0.061924	-0.267408	1.25590
3	-0.193388	1.080760	2.03295
4	1.490793	1.269056	-5.91887
5	1.252347	-4.089591	-3.23561
6	-9.835868	-1.871251	7.23364
7	1.411912	7.438081	5.04151
8	25.277595	-3.536296	0
9	-19.183815	0	0
10	-18.437089	0	0
11	27.000895	0	0
12	-8.716324	0	0

TABLE 7. Approximate effects on thermodynamic properties (heat capacity, enthalpy, and entropy) of several substances due to the change in the temperature scale IPTS-68 to the ITS-90. $C_p(x)$, $H(x)$, and $S(x)$ are, respectively, the heat capacity, enthalpy, and entropy based either on the IPTS-68 or on the ITS-90 scale.

$10^2\{C_p(90) - C_p(68)\}/C_p(90)$

T/K	ND_4ReO_4(s)	$BaSnF_4$(s)	α-Al_2O_3(s)	BeO·Al_2O_3(s)	BeO·3Al_2O_3(s)	Mo(s)
16	0.18	0.19	0.23	0.23	0.23	0.23
40	0.02	0.02	0.05	0.05	0.05	0.05
100	-0.01	-0.01	-0.02	-0.02	-0.02	-0.01
200	0.01	0.01	0.00	0.00	0.00	0.01
300	0.03	0.02	0.03	0.03	0.03	0.02
400	-	0.02	0.02	0.02	0.02	0.02
500	-	0.00	0.00	0.00	0.00	0.00
650	-	0.02	0.02	0.02	0.02	0.01
800	-	-	0.04	0.04	0.04	0.04
850	-	-	0.04	0.04	0.04	0.04
900	-	-	0.00	0.00	0.00	0.00
920	-	-	-0.44	-0.44	-0.44	-0.44
950	-	-	-0.44	-0.45	-0.45	-0.47
980	-	-	-0.40	-0.40	-0.40	-0.40
1000	-	-	-0.25	-0.24	-0.25	-0.25
1020	-	-	-0.21	-0.20	-0.21	-0.21
1050	-	-	-0.01	0.00	-0.01	-0.01
1080	-	-	0.15	0.15	0.14	0.14
1100	-	-	0.34	0.34	0.34	0.34
1150	-	-	0.34	0.34	0.34	0.34
1200	-	-	0.20	0.20	0.20	0.20
1300	-	-	0.10	0.10	0.10	0.11
1600	-	-	0.05	0.05	0.05	0.05
2000	-	-	0.06	0.07	0.07	0.08
2150	-	-	0.06	0.07	0.07	0.08
2400	-	-	-	-	-	0.10
2600	-	-	-	-	-	0.12
2800	-	-	-	-	-	0.15

$10^2\{H(90) - H(68)\}/H(90)$

T/K	ND_4ReO_4(s)	$BaSnF_4$(s)	α-Al_2O_3(s)	BeO·Al_2O_3(s)	BeO·3Al_2O_3(s)	Mo(s)
16	0.09	0.09	0.10	0.10	0.10	0.08
40	0.04	0.04	0.07	0.06	0.06	0.06
100	-0.02	-0.02	-0.04	-0.04	-0.03	-0.03
200	-0.01	-0.01	-0.02	-0.02	-0.02	-0.01
300	0.00	0.00	0.01	0.01	0.01	0.00
400	-	0.01	0.02	0.02	0.02	0.01
500	-	0.01	0.02	0.02	0.02	0.01
650	-	0.01	0.01	0.01	0.01	0.01
800	-	-	0.02	0.02	0.02	0.01
850	-	-	0.02	0.02	0.02	0.02
900	-	-	0.02	0.02	0.02	0.02
920	-	-	0.01	0.01	0.01	0.01
950	-	-	-0.02	-0.01	-0.01	-0.01
980	-	-	-0.03	-0.03	-0.03	-0.03

TABLE 7 (continued)

$10^2\{H(90) - H(68)\}/H(90)$

T/K	ND_4ReO_4(s)	$BaSnF_4$(s)	α-Al_2O_3(s)	BeO·Al_2O_3(s)	BeO·3Al_2O_3(s)	Mo(s)
1000	-	-	-0.04	-0.04	-0.04	-0.04
1020	-	-	-0.05	-0.05	-0.05	-0.04
1050	-	-	-0.05	-0.05	-0.05	-0.04
1080	-	-	-0.04	-0.04	-0.04	-0.04
1100	-	-	-0.03	-0.03	-0.03	-0.03
1150	-	-	-0.01	-0.01	-0.01	-0.01
1200	-	-	0.01	0.01	0.01	0.01
1300	-	-	0.02	0.02	0.02	0.02
1600	-	-	0.03	0.03	0.03	0.03
2000	-	-	0.04	0.04	0.04	0.04
2150	-	-	0.04	0.04	0.04	0.04
2400	-	-	-	-	-	0.05
2600	-	-	-	-	-	0.06
2800	-	-	-	-	-	0.06

$10^2\{S(90) - S(68)\}/S(90)$

T/K	ND_4ReO_4(s)	$BaSnF_4$(s)	α-Al_2O_3(s)	BeO·Al_2O_3(s)	BeO·3Al_2O_3(s)	Mo(s)
16	0.11	0.11	0.09	0.11	0.12	0.05
40	0.03	0.03	0.05	0.05	0.06	0.05
100	0.00	0.00	-0.02	-0.02	-0.02	0.00
200	-0.01	0.00	-0.02	-0.02	-0.02	-0.01
300	0.00	0.00	0.00	0.00	0.00	0.00
400	-	0.01	0.01	0.01	0.01	0.01
500	-	0.01	0.01	0.01	0.01	0.01
650	-	0.01	0.01	0.01	0.01	0.01
800	-	-	0.01	0.01	0.01	0.01
850	-	-	0.01	0.01	0.01	0.01
900	-	-	0.01	0.01	0.01	0.01
920	-	-	0.01	0.01	0.01	0.01
950	-	-	0.00	0.01	0.00	0.00
980	-	-	-0.01	-0.01	-0.01	-0.01
1000	-	-	-0.02	-0.01	-0.01	-0.01
1020	-	-	-0.02	-0.01	-0.01	-0.01
1050	-	-	-0.02	-0.01	-0.01	-0.01
1080	-	-	-0.02	-0.01	-0.01	-0.01
1100	-	-	-0.01	-0.01	-0.01	-0.01
1150	-	-	0.00	0.00	0.00	0.00
1200	-	-	0.01	0.01	0.01	0.01
1300	-	-	0.01	0.02	0.02	0.01
1600	-	-	0.02	0.02	0.02	0.01
2000	-	-	0.02	0.02	0.02	0.02
2150	-	-	0.02	0.03	0.03	0.02
2400	-	-	-	-	-	0.02
2600	-	-	-	-	-	0.03
2800	-	-	-	-	-	0.03

TABLE 8. Approximate effects on thermodynamic properties (heat capacity, enthalpy, and entropy) of several substances due to the change in the temperature scale IPTS-48 to the ITS-90. C_p(x), H(x), and S(x) are, respectively, the heat capacity, enthalpy, and entropy based either on the IPTS-48 or on the ITS-90 scale.

$10^2\{C_p(90) - C_p(48)\}/C_p(90)$

T/K	ND_4ReO_4(s)	$BaSnF_4$(s)	α-Al_2O_3(s)	BeO·Al_2O_3(s)	BeO·3Al_2O_3(s)	Mo(s)
100	0.02	0.03	-0.01	-0.01	0.00	0.02
150	-0.10	-0.10	-0.11	-0.11	-0.11	-0.10
200	0.00	-0.01	-0.03	-0.03	-0.03	-0.01
250	0.08	0.08	0.07	0.07	0.07	0.08
300	0.04	0.04	0.04	0.04	0.04	0.04
350	-	0.02	0.02	0.02	0.02	0.01
400	-	-0.03	-0.03	-0.03	-0.03	-0.03
500	-	-0.03	-0.03	-0.03	-0.03	-0.03
650	-	0.02	0.02	0.02	0.02	0.02
800	-	-	-0.01	-0.01	-0.01	-0.01
850	-	-	-0.06	-0.08	-0.08	-0.06
900	-	-	-0.16	-0.16	-0.16	-0.16
920	-	-	-0.70	-0.70	-0.70	-0.70
950	-	-	-0.82	-0.82	-0.82	-0.82
980	-	-	-0.71	-0.71	-0.71	-0.71
1000	-	-	-0.48	-0.48	-0.49	-0.49
1020	-	-	-0.51	-0.51	-0.51	-0.51
1050	-	-	-0.33	-0.33	-0.33	-0.34
1080	-	-	-0.10	-0.10	-0.10	-0.10
1100	-	-	0.08	0.09	0.08	0.08
1150	-	-	0.20	0.21	0.20	0.19
1200	-	-	-0.15	-0.14	-0.15	-0.15
1600	-	-	-0.16	-0.16	-0.17	-0.19
2000	-	-	-0.15	-0.16	-0.16	-0.21
2150	-	-	-0.15	-0.16	-0.16	-0.22
2400	-	-	-	-	-	-0.24
2600	-	-	-	-	-	-0.27
2800	-	-	-	-	-	-0.49

$10^2\{H(90) - H(48)\}/H(90)$

T/K	ND_4ReO_4(s)	$BaSnF_4$(s)	α-Al_2O_3(s)	BeO·Al_2O_3(s)	BeO·3Al_2O_3(s)	Mo(s)
100	-0.04	-0.04	-0.07	-0.07	-0.07	-0.05
150	-0.02	-0.02	-0.03	-0.03	-0.03	-0.02
200	-0.04	-0.04	-0.07	-0.07	-0.06	-0.04
250	-0.01	-0.01	-0.02	-0.02	-0.02	-0.01
300	0.01	0.01	0.01	0.01	0.01	0.01
350	-	0.01	0.02	0.02	0.02	0.01
400	-	0.01	0.01	0.01	0.01	0.01
500	-	0.00	-0.01	-0.01	-0.01	0.00
650	-	-0.01	-0.01	-0.01	-0.01	-0.01
800	-	-	0.00	0.00	0.00	0.00
850	-	-	0.00	0.00	0.00	0.00
900	-	-	-0.01	-0.01	-0.01	-0.01
920	-	-	-0.03	-0.03	-0.03	-0.03
950	-	-	-0.06	-0.07	-0.07	-0.06
980	-	-	-0.09	-0.09	-0.09	-0.08

TABLE 8 (continued)

$10^2\{H(90) - H(48)\}/H(90)$

T/K	ND_4ReO_4(s)	$BaSnF_4$(s)	α-Al_2O_3(s)	BeO·Al_2O_3(s)	BeO·3Al_2O_3(s)	Mo(s)
1000	-	-	-0.11	-0.11	-0.11	-0.09
1020	-	-	-0.12	-0.12	-0.12	-0.10
1050	-	-	-0.13	-0.13	-0.13	-0.11
1080	-	-	-0.13	-0.13	-0.13	-0.12
1100	-	-	-0.13	-0.13	-0.13	-0.11
1150	-	-	-0.12	-0.12	-0.11	-0.10
1200	-	-	-0.11	-0.11	-0.11	-0.10
1600	-	-	-0.12	-0.12	-0.12	-0.12
2000	-	-	-0.13	-0.13	-0.13	-0.14
2150	-	-	-0.13	-0.14	-0.14	-0.15
2400	-	-	-	-	-	-0.16
2600	-	-	-	-	-	-0.18
2800	-	-	-	-	-	-0.20

$10^2\{S(90) - S(48)\}/S(90)$

T/K	ND_4ReO_4(s)	$BaSnF_4$(s)	α-Al_2O_3(s)	BeO·Al_2O_3(s)	BeO·3Al_2O_3(s)	Mo(s)
100	0.00	0.00	0.00	-0.01	-0.01	0.00
150	0.00	0.00	-0.01	-0.01	-0.01	0.00
200	-0.02	-0.02	-0.05	-0.05	-0.05	-0.02
250	-0.01	0.00	-0.02	-0.02	-0.02	-0.01
300	0.00	0.01	0.00	0.00	0.00	0.01
350	-	0.01	0.01	0.01	0.01	0.01
400	-	0.01	0.01	0.01	0.01	0.01
500	-	0.00	0.00	0.00	0.00	0.00
650	-	0.00	-0.01	-0.01	-0.01	0.00
800	-	-	0.00	0.00	0.00	0.00
850	-	-	0.00	0.00	0.00	0.00
900	-	-	-0.01	-0.01	-0.01	0.00
920	-	-	-0.01	-0.02	-0.02	-0.01
950	-	-	-0.03	-0.03	-0.03	-0.02
980	-	-	-0.04	-0.04	-0.04	-0.03
1000	-	-	-0.05	-0.05	-0.05	-0.03
1020	-	-	-0.06	-0.06	-0.05	-0.04
1050	-	-	-0.06	-0.06	-0.06	-0.04
1080	-	-	-0.07	-0.06	-0.06	-0.04
1100	-	-	-0.06	-0.06	-0.06	-0.04
1150	-	-	-0.06	-0.06	-0.06	-0.04
1200	-	-	-0.06	-0.06	-0.05	-0.04
1600	-	-	-0.08	-0.07	-0.07	-0.06
2000	-	-	-0.09	-0.08	-0.08	-0.07
2150	-	-	-0.09	-0.09	-0.09	-0.08
2400	-	-	-	-	-	-0.09
2600	-	-	-	-	-	-0.09
2800	-	-	-	-	-	-0.11

Acknowledgements The authors thank Drs. R.E. Bedford, P. Bloembergen and R.L. Rusby for sending us the equations for representing the differences in temperature scales prior to publication. G.W. Burns and G.F. Strouse kindly provided us their recent results on the differences between ITS-90 and ITS-68 from 630 °C to 1064 °C. We are grateful to Mr. L. Bowness for his assistance with the calculations. Helpful comments were received from Drs. L. Crovini, K.M. de Reuck, M. Ewing, G.T. Furukawa, B.W. Mangum, P.A.G. O'Hare, F. Pavese, T.J. Quinn, F. Righini, and W.A. Wakeham.

REFERENCES

1. *Procès-verbaux du Comité International des Poids et Mesures*, Bureau International des Poids et Mesures, Pavillon de Breteuil, Sèvres, France (1990).
2. H. Preston-Thomas, *Metrologia 27*, 3-10 (1990); *Metrologia 27*, 107 (1990).
3. M.L. McGlashen, *J. Chem. Thermodyn. 22*, 653-663 (1990).
4. H. Preston-Thomas, P. Bloembergen, and T.J. Quinn, *Supplementary Information for the International Temperature Scale of 1990*, Bureau International des Poids et Mesures, Pavillon de Breteuil, Sèvres, France (1990).
5. R.E. Bedford, G. Bonnier, H. Maas and F. Pavese, *Techniques for Approximating the International Temperature Scale of 1990*, Bureau International des Poids et Mesures, Pavillon de Breteuil, Sèvres, France (1990).
6. B.W. Mangum and G.T. Furukawa, *Guidelines for Realizing the International Temperature Scale of 1990 (ITS-90)*, NIST Technical Note 1265, National Institute of Standards and Technology, Gaithersburg, Maryland (1990).
7. H. Preston-Thomas, P. Bloembergen, and T. Quinn, *Supplementary Information for the IPTS-68 and the EPT-76*, Bureau International des Poids et Mesures, Pavillon de Breteuil, Sèvres, France (1983).
8. *NAG Fortran Library Manual - Mark 13*, Numerical Algorithms Group, Ltd., Oxford (1988).
9. R. Boisvert, S.E. Howe, D.K. Kahaner, and J.L. Springmann, *Guide to Available Mathematical Software*, NBSIR 90-4237, National Institute of Standards and Technology, Gaithersburg, Maryland (1990).
10. J.L. Riddle, G.T. Furukawa, and H.H. Plumb, *Platinum Resistance Thermometry*, Natl. Bur. Stand. Monograph 126, U.S. Government Printing Office, Washington, D.C. (1972).
11. R.L. Rusby, *J. Chem. Thermodyn. 23*, 1153-1162 (1991).
12. T.B. Douglas, *J. Res. Natl. Bur. Stand., Sect. A 73*, 451-470 (1969).
13. R.J.C. Brown, J.E. Callanan, R.D. Weir, and E.F. Westrum, Jr., *J. Chem. Thermodyn. 18*, 787-792 (1986).
14. J.E. Callanan, R.D. Weir, and E.F. Westrum, Jr., *Internat. J. Thermophys. 9*, 1091-1100 (1988).
15. J.E. Callanan and R.D. Weir, *J. Chem. Thermodyn. 23*, 411-420 (1991).
16. D.A. Ditmars, S. Ishihara, S.S. Chang, G. Bernstein, and E.D. West, *J. Res. Natl. Bur. Stand. 87*, 159-163 (1982).
17. S.S. Chang, *Proceedings of the Seventh Symposium on Thermophysical Properties, ASME*, held at the National Bureau of Standards, Gaithersburg, Maryland, May 10-12, 1977, pp. 83-90.
18. D.A. Ditmars and T.B. Douglas, *J. Res. Natl. Bur. Stand., Sect. A 75*, 401-420 (1971).
19. G.T. Furukawa and W.G. Saba, *J. Res. Natl. Bur. Stand., Sect. A 69*, 13-18 (1965).
20. D.A. Ditmars and T.B. Douglas, *J. Res. Natl. Bur. Stand., Sect. A 71*, 89-95 (1967).
21. G.T. Furukawa and W.G. Saba, *J. Res. Natl. Bur. Stand., Sect. A 71*, 3-8 (1967).
22. D.A. Ditmars and T.B. Douglas, *J. Res. Natl. Bur. Stand., Sect. A 71*, 97-103 (1967).
23. K. Klusius and P. Franzosini, *Z. Naturforsch., A: Phys. Phys. Chem. Kosmophys. 14*, 991-105 (1959).
24. D.A. Ditmars, A. Cezairliyan, S. Ishihara, and T.B. Douglas, *Enthalpy and Heat Capacity Standard Reference Material: Molybdenum SRM 781, from 273 to 2800 K*, Natl. Bur. Stand. Spec. Pub. 260-55, U.S. Government Printing Office, Washington, D.C. (1977).
25. G.T. Furukawa and M.L. Reilly, *J. Res. Natl. Bur. Stand., Sect. A 69*, 5-12 (1965).
26. G.T. Furukawa and M.L. Reilly, in *Temperature: Its Measurement and Control in Science and Industry*, Vol. 4, (H.H. Plumb, editor-in-chief), pp. 27-36 Instrument Society of America, Pittsburgh, Pennsylvania (1972).

27. D.C. Ginnings, in *Precision Measurement and Calibration: Selected NBS Papers on Heat*, Natl. Bur. Stand. Spec. Pub. 300 - Vol. 6, (D.C. Ginnings, editor), pp. 1-14, U.S. Government Printing Office, Washington, D.C. (1970).
28. N.S. Osborne, H.F. Stimson, and D.C. Ginnings, *J. Res. Natl. Bur. Stand. (U.S.) 23*, 197-270 (1939).
29. G.W. Burns, G.F. Strouse, B.W. Mangum, M.C. Croarkin, W.F. Guthrie, P. Marcarino, M. Battuello, H.K. Lee, J.C. Kim, K.S. Gam, C. Rhee, M. Chattle, M. Arai, H. Sakurai, A.I. Pokhodun, N.P. Moiseeva, S.A. Perevalova, M.J. deGroot, J. Zhang, K. Fan, and S. Wu, *New reference function for platinum-10% rhodium versus platinum (type S) thermocouples based on the ITS-90. Part I: Experimental procedures*, in *Temperature: Its Measurement and Control in Science and Industry*, Vol. 6 (J.F. Schooley, editor), American Institute of Physics, New York, in press.
30. G.W. Burns, G.F. Strouse, B.W. Mangum, M.C. Croarkin, W.F. Guthrie, P. Marcarino, M. Battuello, H.K. Lee, J.C. Kim, K.S. Gam, C. Rhee, M. Chattle, M. Arai, H. Sakurai, A.I. Pokhodun, N.P. Moiseeva, S.A. Perevalova, M.J. deGroot, J. Zhang, K. Fan, and S. Wu, *New reference function for platinum-10% rhodium versus platinum (type S) thermocouples based on the ITS-90. Part II: Results and discussion*, in *Temperature: Its Measurement and Control in Science and Industry*, Vol. 6 (J.F. Schooley, editor), American Institute of Physics, New York, in press.
31. W.F. Guthrie, M.C. Croarkin, G.W. Burns, G.F. Strouse, P. Marcarino, M. Battuello, H.K. Lee, J.C. Kim, K.S. Gam, C. Rhee, M. Chattle, M. Arai, H. Sakurai, A.I. Pokhodun, N.P. Moiseeva, S.A. Perevalova, M.J. deGroot, J. Zhang, K. Fan, and S. Wu, *Statistical analysis of type S thermocouple measurements on the International Temperature Scale of 1990*, in *Temperature: Its Measurement and Control in Science and Industry*, Vol. 6 (J.F. Schooley, editor), American Institute of Physics, New York, in press.