

The International Temperature Scale of 1990 (ITS-90)

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The International Temperature Scale of 1990 (ITS-90) is introduced, is operationally defined for different ranges from 0.65 K upwards in terms of vapour-pressure thermometry, gas thermometry, platinum resistance thermometry, and optical pyrometry, and is compared numerically and graphically with the IPTS-68 (T_{68}), and also numerically with the EPT-76 (T_{76}).

1. Introduction

The present article on the International Temperature Scale of 1990 (ITS-90) is a version prepared for readers of this *Journal* of the official publications in *Metrologia*⁽¹⁾ and the *Procès-verbaux du Comité International des Poids et Mesures*.⁽²⁾

The International Temperature Scale of 1990 (ITS-90) was adopted by the International Committee of Weights and Measures at its meeting in 1989, in accordance with the request embodied in Resolution 7 of the 18th General Conference of Weights and Measures of 1987. The ITS-90 supersedes the International Practical Temperature Scale of 1968 (amended edition of 1975) (IPTS-68) and the 1976 Provisional 0.5 K to 30 K Temperature Scale (EPT-76).

The symbol for the fundamental physical quantity called thermodynamic temperature is T . The SI base unit of thermodynamic temperature is the kelvin, symbol K, defined as the fraction $1/273.16$ of the thermodynamic temperature at the triple point of water.

The symbol for the corresponding physical quantity called international temperature and defined by the ITS-90 is T_{90} . The unit of the physical quantity T_{90} is the kelvin, symbol K, just as for thermodynamic temperature T .

2. Principles of the ITS-90

The ITS-90 extends upwards from 0.65 K to the highest temperature practically measurable in terms of the Planck radiation law using monochromatic radiation. The ITS-90 comprises a number of ranges and sub-ranges throughout each of which

temperatures T_{90} are defined. Several of these ranges or sub-ranges overlap, and where such overlapping occurs differing definitions of T_{90} exist; these differing definitions have equal status. For measurements of the very highest precision there may be detectable numerical differences between measurements made at the same temperature but in accordance with differing definitions. Similarly, even using one definition, at a temperature between defining fixed temperatures two acceptable interpolating instruments (*e.g.* resistance thermometers) may give detectably differing numerical values of T_{90} . In virtually all cases these differences are of negligible practical importance and are at the minimum level consistent with a scale of no more than reasonable complexity; for further information on this point see reference 3.

The ITS-90 has been constructed in such a way that, throughout its range, for any given temperature the numerical value of T_{90} is a close approximation to the numerical value of T according to best estimates made at the time the scale was adopted. By comparison with direct measurements of thermodynamic temperatures, measurements of T_{90} are more easily made with a given precision.

There are significant numerical differences between the values of T_{90} and the corresponding values of T_{68} measured on the IPTS-68; see figure 1 and table 6. Similarly there were differences between the IPTS-68 and the IPTS-48, and between the ITS-48 and the ITS-27. See the appendix in reference 1 and for more detailed information reference 3.

3. Definition of the ITS-90

Between 0.65 K and 5.0 K, T_{90} is defined in terms of the relations between vapour pressure and temperature for ^3He and ^4He . Between 3.0 K and the triple-point temperature of neon (24.5561 K), T_{90} is defined by means of a helium gas thermometer calibrated at three experimentally realizable temperatures having assigned numerical values ("defining fixed temperatures") and using specified interpolation procedures. Between the triple-point temperature of equilibrium hydrogen (13.8033 K) and the freezing temperature of silver (1234.93 K), T_{90} is defined by means of platinum resistance thermometers calibrated at specified sets of defining fixed temperatures and using specified interpolation procedures. Above the freezing temperature of silver (1234.93 K), T_{90} is defined in terms of a defining fixed temperature and the Planck radiation law.

The defining fixed temperatures of the ITS-90 are listed in table 1. The effects of pressure, arising from significant depths of immersion of the sensor or from other causes, on most of these temperatures are given in table 2.

In the range 0.65 K to 5.0 K, T_{90} is defined in terms of the vapour pressure p of ^3He and of ^4He using equations of the form:

$$T_{90}/\text{K} = A_0 + \sum_{i=1}^9 A_i [\{\ln(p/\text{Pa}) - B\}/C]^i \quad (1)$$

The values of the parameters A_0 , A_i , B , and C are given in table 3 for ^3He in the range 0.65 K to 3.2 K, and for ^4He in the ranges 1.25 K to 2.1768 K (the λ temperature) and 2.1768 K to 5.0 K.

In the range 3.0 K to the triple-point temperature of neon (24.5561 K), T_{90} is defined in terms of a ^3He or a ^4He gas thermometer of the constant-volume type that

TABLE 1. The defining fixed temperatures of the ITS-90

Step	T_{90}/K	Substance ^a	Kind ^b	$W_i(T_{90})$
1	3 to 5	He	V	
2	13.8033	e-H ₂	T	0.001 190 07
3	≈ 17	e-H ₂ (or He)	V (or G)	
4	≈ 20.3	e-H ₂ (or He)	V (or G)	
5	24.5561	Ne	T	0.008 449 74
6	54.3584	O ₂	T	0.091 718 04
7	83.8058	Ar	T	0.215 859 75
8	234.3156	Hg	T	0.844 142 11
9	273.16	H ₂ O	T	1.000 000 00
10	302.9146	Ga	M	1.118 138 89
11	429.7485	In	F	1.609 801 85
12	505.078	Sn	F	1.892 797 68
13	692.677	Zn	F	2.568 917 30
14	933.473	Al	F	3.376 008 60
15	1234.93	Ag	F	4.286 420 53
16	1337.33	Au	F	
17	1357.77	Cu	F	

^a All substances except ³He are of natural nuclidic composition; e-H₂ is hydrogen at the equilibrium mole fractions of o-H₂ and p-H₂.

^b For complete definitions and advice on the realization of these various temperatures see reference 3. The symbols have the following meanings:

V: vapour pressure as a function of temperature;

T: triple-point temperature (at which solid, liquid, and vapour phases are in equilibrium);

G: gas thermometry;

M, F: melting temperature, freezing temperature (at a pressure of 101 325 Pa, at which the solid and liquid phases are in equilibrium).

TABLE 2. Effect of pressure p on some defining fixed temperatures T_{90} . The reference pressure for melting and freezing temperatures is 101 325 Pa. For triple-point temperatures (T) the effect of pressure is a consequence only of the hydrostatic head h_l of liquid in the cell

Substance	Assigned value of equilibrium temperature T_{90} K	Pressure effect	
		$\frac{dT_{90}}{dp}$ $10^{-8} \cdot \text{K} \cdot \text{Pa}^{-1}$	$\frac{dT_{90}}{dh_l}$ $\text{mK} \cdot \text{m}^{-1}$
e-Hydrogen (T)	13.8033	34	0.25
Neon (T)	24.5561	16	1.9
Oxygen (T)	54.3584	12	1.5
Argon (T)	83.8058	25	3.3
Mercury (T)	234.3156	5.4	7.1
Water (T)	273.16	-7.5	-0.73
Gallium	302.9146	-2.0	-1.2
Indium	429.7485	4.9	3.3
Tin	505.078	3.3	2.2
Zinc	692.677	4.3	2.7
Aluminium	933.473	7.0	1.6
Silver	1234.93	6.0	5.4
Gold	1337.33	6.1	10
Copper	1357.77	3.3	2.6

He-4 lambda point pressure = 5.0418 kPa = 37.81661 torr

656

M. L. McGLASHAN

TABLE 3. Values of the parameters for the helium vapour-pressure equations (1), and the temperature range for which each equation, identified by its set of parameters, is valid

	³ He 0.65 K to 3.2 K	⁴ He 1.25 K to 2.1768 K	⁴ He 2.1768 K to 5.0 K
<i>A</i> ₀	1.053 447	1.392 408	3.146 631
<i>A</i> ₁	0.980 106	0.527 153	1.357 655
<i>A</i> ₂	0.676 380	0.166 756	0.413 923
<i>A</i> ₃	0.372 692	0.050 988	0.091 159
<i>A</i> ₄	0.151 656	0.026 514	0.016 349
<i>A</i> ₅	−0.002 263	0.001 975	0.001 826
<i>A</i> ₆	0.006 596	−0.017 976	−0.004 325
<i>A</i> ₇	0.088 966	0.005 409	−0.004 973
<i>A</i> ₈	−0.004 770	0.013 259	0
<i>A</i> ₉	−0.054 943	0	0
<i>B</i>	7.3	5.6	10.3
<i>C</i>	4.3	2.9	1.9

has been calibrated at the three temperatures: the triple-point temperature of neon (24.5561 K), the triple-point temperature of equilibrium hydrogen (13.8033 K), and a temperature between 3.0 K and 5.0 K. This last temperature is determined using a ³He or a ⁴He vapour-pressure thermometer as specified in the preceding paragraph. From 4.2 K to 24.5561 K, with ⁴He as the thermometric gas, *T*₉₀ is defined by the relation:

$$T_{90} = a + bp + cp^2, \quad (2)$$

where *p* is the pressure in the gas thermometer and *a*, *b*, and *c* are coefficients the numerical values of which are obtained from measurements made at the three defining fixed temperatures specified in the preceding paragraph, but with the further restriction that the lowest of these temperatures lies between 4.2 K and 5.0 K. From 3.0 K to 24.5561 K, for a ³He gas thermometer, and for a ⁴He gas thermometer used below 4.2 K, the non-ideality of the gas must be accounted for explicitly, using the appropriate second virial coefficient *B*₃(*T*₉₀) or *B*₄(*T*₉₀), and *T*₉₀ is defined by the relation:

$$T_{90} = (a + bp + cp^2)/\{1 + B_x(T_{90})/V_m\}, \quad (3)$$

where *p* is the pressure in the gas thermometer, *a*, *b*, and *c* are coefficients the numerical values of which are obtained from measurements at three defining temperatures specified in the preceding paragraph, *V*_m is the molar volume of the gas, *x* is 3 or 4 according to the nuclide of helium used, and the values of the second virial coefficients are given by the relations:

for ³He:

$$B_3(T_{90})/(\text{m}^3 \cdot \text{mol}^{-1}) = \{16.69 - 336.98(T_{90}/\text{K})^{-1} + 91.04(T_{90}/\text{K})^{-2} - 13.82(T_{90}/\text{K})^{-3}\} \cdot 10^{-6}, \quad (4a)$$

and for ⁴He:

$$B_4(T_{90})/(\text{m}^3 \cdot \text{mol}^{-1}) = \{16.708 - 374.05(T_{90}/\text{K})^{-1} - 383.53(T_{90}/\text{K})^{-2} + 1799.2(T_{90}/\text{K})^{-3} - 4033.2(T_{90}/\text{K})^{-4} + 3252.8(T_{90}/\text{K})^{-5}\} \cdot 10^{-6}. \quad (4b)$$

The accuracy with which T_{90} can be realized using equations (2) and (3) depends on the design of the gas thermometer and the molar volume used for the gas. Design criteria and current good practice required to achieve a selected accuracy are given in reference 3.

In the range from the triple-point temperature of equilibrium hydrogen (13.8033 K) to the freezing temperature of silver (1234.93 K), T_{90} is defined by means of a platinum resistance thermometer calibrated at specified sets of defining fixed temperatures and using specified reference and deviation functions for interpolation at intermediate temperatures.

No single platinum resistance thermometer can provide high accuracy, or is likely even to be usable, over all of the temperature range 13.8033 K to 1234.93 K. The choice of temperature range, or ranges, from those listed below for which a particular thermometer can be used is normally limited by its construction.

For practical details and current good practice, in particular concerning types of thermometer available, their acceptable operating ranges, probable accuracies, permissible leakage resistances, resistance values, and thermal treatments, see reference 3. It is particularly important to take account of the appropriate thermal treatments that should be followed each time a platinum resistance thermometer is subjected to a temperature above about 690 K.

Temperatures are determined in terms of the ratio $W(T_{90})$ of the resistance $R(T_{90})$ at a temperature T_{90} and the resistance $R(273.16 \text{ K})$ at the triple-point temperature of water:

$$W(T_{90}) = R(T_{90})/R(273.16 \text{ K}).\dagger \quad (5)$$

An acceptable platinum resistance thermometer must be made from pure strain-free platinum, and it must satisfy at least one of the two relations:

$$W(302.9146 \text{ K}) \geq 1.11807, \quad (6a)$$

$$W(234.3156 \text{ K}) \leq 0.844235. \quad (6b)$$

An acceptable platinum resistance thermometer that is to be used up to the freezing temperature of silver must also satisfy the relation:

$$W(1234.93 \text{ K}) \geq 4.2844. \quad (6c)$$

In each of the resistance-thermometer ranges, T_{90} is obtained from $W_r(T_{90})$ as given by the appropriate reference function: equations (7b) or (8b) below, and the deviation $\{W(T_{90}) - W_r(T_{90})\}$. At the defining fixed temperatures this deviation is obtained directly from the calibration of the thermometer; at intermediate temperatures it is obtained by means of the appropriate deviation function given by equation (10), (11), or (12), below.

For the range 13.8033 K to 273.16 K the reference function:

$$\ln\{W_r(T_{90})\} = A_0 + \sum_{i=1}^{12} A_i [\{\ln(T_{90}/273.16 \text{ K}) + 1.5\}/1.5]^i, \quad (7a)$$

is defined. An inverse function, equivalent to equation (7a) to within 0.1 mK, is

$$T_{90}/273.16 \text{ K} = B_0 + \sum_{i=1}^{15} B_i [\{W_r(T_{90})^{1/6} - 0.65\}/0.35]^i. \quad (7b)$$

[†] Note that this definition of $W(T_{90})$ differs from the corresponding definition used in the ITS-27, ITS-48, IPTS-48, and IPTS-68; for all of these earlier scales $W(T)$ was defined in terms of a reference temperature of "0 °C", which since 1954 has itself been defined as 273.15 K.

TABLE 4. The parameters A_0 , A_i , B_0 , B_i , C_0 , C_i , D_0 , and D_i in the reference functions of equations (7a), (7b), (8a), and (8b), respectively

i	A_i	B_i	C_i	D_i
0	-2.135 347 29	0.183 324 722	2.781 572 54	439.932 854
1	3.183 247 20	0.240 975 303	1.646 509 16	472.418 020
2	-1.801 435 97	0.209 108 771	-0.137 143 90	37.684 494
3	0.717 272 04	0.190 439 972	-0.006 497 67	7.472 018
4	0.503 440 27	0.142 648 498	-0.002 344 44	2.920 828
5	-0.618 993 95	0.077 993 465	0.005 118 68	0.005 184
6	-0.053 323 22	0.012 475 611	0.001 879 82	-0.963 864
7	0.280 213 62	-0.032 267 127	-0.002 044 72	-0.188 732
8	0.107 152 24	-0.075 291 522	-0.000 461 22	0.191 203
9	-0.293 028 65	-0.056 470 670	0.000 457 24	0.049 025
10	0.044 598 72	0.076 201 285		
11	0.118 686 32	0.123 893 204		
12	-0.052 481 34	-0.029 201 193		
13		-0.091 173 542		
14		0.001 317 696		
15		0.026 025 526		

The values of the parameters A_0 , B_0 , A_i , and B_i are given in table 4. A thermometer may be calibrated for use throughout this range or, using progressively fewer calibration temperatures, for ranges with low-temperature bounds of 24.5561 K, 54.3584 K, and 83.8058 K, all with an upper bound of 273.16 K.

For the range 273.15 K to 1234.93 K the reference function:

$$W_r(T_{90}) = C_0 + \sum_{i=1}^9 C_i \{(T_{90} - 754.15 \text{ K})/481 \text{ K}\}^i, \quad (8a)$$

is defined. An inverse function, equivalent to equation (8a) to within 0.13 mK is

$$(T_{90}/\text{K}) - 273.15 = D_0 + \sum_{i=1}^9 D_i [\{W_r(T_{90}) - 2.64\}/1.64]^i. \quad (8b)$$

The values of the parameters C_0 , D_0 , C_i , and D_i are given in table 4. A thermometer may be calibrated for use throughout this range or, using fewer calibration temperatures, for ranges with upper bounds of 933.473 K, 692.677 K, 505.078 K, 429.7485 K, or 302.9146 K, all with a lower bound of 273.15 K.

For the range 234.3156 K to 302.9146 K a thermometer may be calibrated at these temperatures and at the triple-point temperature of water; both reference functions {equations (7) and (8)} are required to cover this range.

The defining fixed temperatures and deviation functions for the various ranges are given below, and in summary form in table 5.

For the range from 13.8033 K to 273.16 K the thermometer is calibrated at the triple-point temperatures of equilibrium hydrogen (13.8033 K), neon (24.5561 K), oxygen (54.3584 K), argon (83.8058 K), mercury (234.3156 K), and water (273.16 K), and at two additional temperatures close to 17.0 K and 20.3 K. These last two may be determined *either* by using a gas thermometer as described above, in which case the two temperatures must lie within the ranges 16.9 K to 17.1 K and 20.2 K to 20.4 K, respectively, *or* by using the relation of vapour pressure and temperature for

TABLE 5. Deviation functions and calibration steps (see table 1) for platinum resistance thermometers in the various ranges in which they define T_{90}

(a) Ranges with an upper bound of 273.16 K:		
Lower bound	Deviation function	Calibration steps
13.8033 K	Equation (10) with $n = 2$	2 to 9
24.5561 K	Equation (10) with $c_4 = c_5 = n = 0$	2 and 5 to 9
54.3584 K	Equation (10) with $c_2 = c_3 = c_4 = c_5 = 0, n = 1$	6 to 9
83.8058 K	Equation (11)	7 to 9
(b) Ranges with a lower bound of 273.15 K:		
Upper bound	Deviation function	Calibration steps
1234.93 K	Equation (12)	9 and 12 to 15 ^a
933.473 K	Equation (12) with $d = 0$	9 and 12 to 14
692.677 K	Equation (12) with $c = d = 0$	9, 12, and 13
505.078 K	Equation (12) with $c = d = 0$	9, 11, and 12
429.7485 K	Equation (12) with $b = c = d = 0$	9 and 11
302.9146 K	Equation (12) with $b = c = d = 0$	9 and 10
(c) Range from 234.3156 K to 302.9146 K:		
	Deviation function	Calibration steps
	Equation (12) with $c = d = 0$	8 to 10

^a Calibration steps 9 and 12 to 14 are used with $d = 0$ for $T_{90} \leq 933.473$ K; the values of a , b , and c thus obtained are retained for $T_{90} > 933.473$ K, with d being determined from calibration step 15.

equilibrium hydrogen, in which case the two temperatures must lie within the ranges 17.025 K to 17.045 K and 20.26 K to 20.28 K, respectively, with the precise values being determined from equations (9a) and (9b), respectively:

$$(T_{90}/\text{K}) - 17.035 = \{(p/\text{kPa}) - 33.3213\}/13.32, \quad (9a)$$

$$(T_{90}/\text{K}) - 20.27 = \{(p/\text{kPa}) - 101.292\}/30. \quad (9b)$$

The deviation function is[‡]

$$W(T_{90}) - W_r(T_{90}) = a\{W(T_{90}) - 1\} + b\{W(T_{90}) - 1\}^2 + \sum_{i=1}^5 c_i [\ln\{W(T_{90})\}]^{i+n}, \quad (10)$$

with values for the coefficients a , b , and c_i being obtained from measurements at the defining fixed temperatures and with $n = 2$. For this range, and for the three sub-ranges which will now be specified, the required values of $W_r(T_{90})$ are obtained from equation (7a) or from table 1.

[‡] This deviation function, and also those of equations (11) and (12) below, may be expressed in terms of W_r rather than W ; for the procedures see reference 3.

For the sub-range 24.5561 K to 273.16 K the thermometer is calibrated at the triple-point temperatures of equilibrium hydrogen (13.8033 K), neon (24.5561 K), oxygen (54.3584 K), argon (83.8058 K), mercury (234.3156 K), and water (273.16 K). The deviation function is given by equation (10) with values of the coefficients a , b , c_1 , c_2 , and c_3 being obtained from measurements at the defining fixed temperatures and with $c_4 = c_5 = n = 0$.

For the sub-range 54.3584 K to 273.16 K the thermometer is calibrated at the triple-point temperatures of oxygen (54.3584 K), argon (83.8058 K), mercury (234.3156 K), and water (273.16 K). The deviation function is given by equation (10) with values for the coefficients a , b , and c_1 being obtained from measurements at the defining fixed temperatures, with $c_2 = c_3 = c_4 = c_5 = 0$ and with $n = 1$.

For the sub-range 83.8058 K to 273.16 K the thermometer is calibrated at the triple-point temperatures of argon (83.8058 K), mercury (234.3156 K), and water (273.16 K). The deviation function is

$$W(T_{90}) - W_r(T_{90}) = a\{W(T_{90}) - 1\} + b\{W(T_{90}) - 1\}\ln\{W(T_{90})\}, \quad (11)$$

with the values of a and b being obtained from measurements at the defining fixed temperatures.

For the range 273.15 K to 1234.93 K the thermometer is calibrated at the triple-point temperature of water (273.16 K) and at the freezing temperatures of tin (505.078 K), zinc (692.677 K), aluminium (933.473 K), and silver (1234.93 K). The deviation function is

$$W(T_{90}) - W_r(T_{90}) = a\{W(T_{90}) - 1\} + b\{W(T_{90}) - 1\}^2 + c\{W(T_{90}) - 1\}^3 + d\{W(T_{90}) - W(933.473 \text{ K})\}^2. \quad (12)$$

For temperatures below the freezing temperature of aluminium $d = 0$, with the values of a , b , and c being determined from the measured deviations from $W_r(T_{90})$ at the freezing temperatures of tin, zinc, and aluminium. From the freezing temperature of aluminium (933.473 K) to the freezing temperature of silver (1234.93 K) the above values of a , b , and c are retained and the value of d is determined from the measured deviation from $W_r(T_{90})$ at the freezing temperature of silver. For this range, and for the five sub-ranges which will now be specified, the required values for $W_r(T_{90})$ are obtained from equation (8a) or from table 1.

For the sub-range from 273.15 K to 933.473 K the thermometer is calibrated at the triple-point temperature of water (273.16 K), and at the freezing temperatures of tin (505.078 K), zinc (692.677 K), and aluminium (933.473 K). The deviation function is given by equation (12), with the values of a , b , and c being determined from measurements at the defining fixed temperatures and with $d = 0$.

For the sub-range from 273.15 K to 692.677 K the thermometer is calibrated at the triple-point temperature of water (273.16 K), and at the freezing temperatures of tin (505.078 K) and zinc (692.677 K). The deviation function is given by equation (12) with the values of a and b being obtained from measurements at the defining fixed temperatures and with $c = d = 0$.

For the sub-range from 273.15 K to 505.078 K the thermometer is calibrated at the triple-point temperature of water (273.16 K), and at the freezing temperatures of

indium (429.7485 K) and tin (505.078 K). The deviation function is given by equation (12) with the values of a and b being obtained from measurements at the defining fixed temperatures and with $c = d = 0$.

For the sub-range from 273.15 K to 429.7485 K the thermometer is calibrated at the triple-point temperature of water (273.16 K), and at the freezing temperature of indium (429.7485 K). The deviation function is given by equation (12) with the value of a being obtained from measurements at the defining fixed temperatures and with $b = c = d = 0$.

For the sub-range from 273.15 K to 302.9146 K the thermometer is calibrated at the triple-point temperature of water (273.16 K), and at the melting temperature of gallium (302.9146 K). The deviation function is given by equation (12) with the value of a being obtained from measurements at the defining fixed temperatures and with $b = c = d = 0$.

For the range from 234.3156 K to 302.9146 K the thermometer is calibrated at the triple-point temperatures of mercury (234.3156 K) and water (273.16 K), and at the melting temperature of gallium (302.9146 K). The deviation function is given by equation (12) with the values of a and b being obtained from measurements at the defining fixed temperatures and with $c = d = 0$. The required values of $W_r(T_{90})$ are obtained from equations (7a) and (8a) for measurements below and above 273.16 K, respectively, or from table 1.

For temperatures above the freezing temperature of silver (1234.93 K) the temperature T_{90} is defined by the Planck radiation equation:

$$L_\lambda(T_{90})/L_\lambda(T_{90,x}) = \{\exp(c_2/\lambda T_{90,x}) - 1\} / \{\exp(c_2/\lambda T_{90}) - 1\}, \quad (13)$$

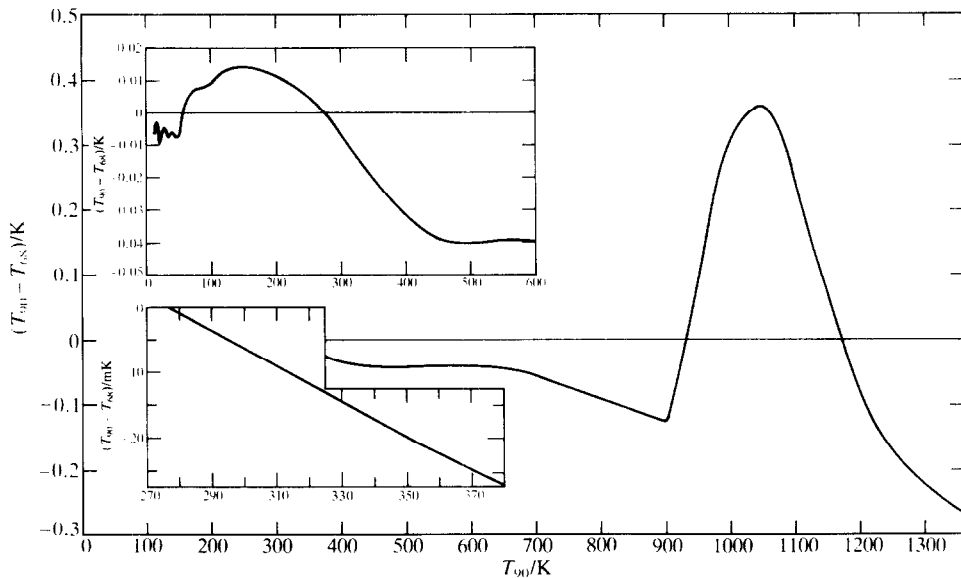


FIGURE 1. The differences $(T_{90} - T_{68})$ between temperatures T_{90} on the ITS-90 and temperatures T_{68} on the IPTS-68 plotted against T_{90} .

TABLE 6. Differences $(T_{90} - T_{76})$ between ITS-90 and EPT-76, and $(T_{90} - T_{68})$ between ITS-90 and IPTS-68

$(T_{90} - T_{76})/\text{mK}$										
T_{90}/K	0	1	2	3	4	5	6	7	8	9
0						-0.1	-0.2	-0.3	-0.4	-0.5
10	-0.6	-0.7	-0.8	-1.0	-1.1	-1.3	-1.4	-1.6	-1.8	-2.0
20	-2.2	-2.5	-2.7	-3.0	-3.2	-3.5	-3.8	-4.1		
$(T_{90} - T_{68})/\text{K}$										
T_{90}/K	0	1	2	3	4	5	6	7	8	9
10					-0.006	-0.003	-0.004	-0.006	-0.008	-0.009
20	-0.009	-0.008	-0.007	-0.007	-0.006	-0.005	-0.004	-0.004	-0.005	-0.006
30	-0.006	-0.007	-0.008	-0.008	-0.008	-0.007	-0.007	-0.007	-0.006	-0.006
40	-0.006	-0.006	-0.006	-0.006	-0.006	-0.007	-0.007	-0.007	-0.006	-0.006
50	-0.006	-0.005	-0.005	-0.004	-0.003	-0.002	-0.001	0.000	+0.001	+0.002
60	+0.003	+0.003	+0.004	+0.004	+0.005	+0.005	+0.006	+0.006	+0.007	+0.007
70	+0.007	+0.007	+0.007	+0.007	+0.007	+0.008	+0.008	+0.008	+0.008	+0.008
80	+0.008	+0.008	+0.008	+0.008	+0.008	+0.008	+0.008	+0.008	+0.008	+0.008
90	+0.008	+0.008	+0.008	+0.008	+0.008	+0.008	+0.008	+0.009	+0.009	+0.009
T_{90}/K	0	10	20	30	40	50	60	70	80	90
100	+0.009	+0.011	+0.013	+0.014	+0.014	+0.014	+0.014	+0.013	+0.012	+0.012
200	+0.011	+0.010	+0.009	+0.008	+0.007	+0.005	+0.003	+0.001	-0.001	-0.004
300	-0.006	-0.009	-0.012	-0.015	-0.017	-0.020	-0.023	-0.025	-0.027	-0.029
400	-0.031	-0.033	-0.035	-0.037	-0.038	-0.039	-0.039	-0.040	-0.040	-0.040
500	-0.040	-0.040	-0.040	-0.040	-0.039	-0.039	-0.039	-0.039	-0.039	-0.039
600	-0.040	-0.040	-0.041	-0.042	-0.043	-0.044	-0.046	-0.047	-0.050	-0.052
700	-0.055	-0.058	-0.061	-0.064	-0.067	-0.071	-0.074	-0.078	-0.082	-0.086
800	-0.089	-0.093	-0.097	-0.100	-0.104	-0.107	-0.111	-0.114	-0.117	-0.121
900	-0.124	-0.09	-0.05	+0.00	+0.05	+0.09	+0.14	+0.19	+0.23	+0.27
1000	+0.30	+0.32	+0.34	+0.36	+0.36	+0.36	+0.35	+0.34	+0.33	+0.30
1100	+0.26	+0.23	+0.19	+0.15	+0.11	+0.07	+0.04	+0.00	-0.02	-0.05
1200	-0.07	-0.09	-0.11	-0.13	-0.15	-0.17	-0.18	-0.19	-0.20	-0.21
1300	-0.22	-0.23	-0.24	-0.25	-0.25	-0.26	-0.26			
T_{90}/K	0	100	200	300	400	500	600	700	800	900
1300		-0.27	-0.31	-0.36	-0.40	-0.45	-0.50	-0.56	-0.62	-0.68
2300	-0.74	-0.81	-0.87	-0.95	-1.02	-1.09	-1.17	-1.26	-1.34	-1.43
3300	-1.52	-1.62	-1.71	-1.81	-1.92	-2.02	-2.13	-2.24	-2.35	

where $T_{90,x}$ refers to any one of the freezing temperatures of silver ($T_{90,\text{Ag}} = 1234.93 \text{ K}$), gold ($T_{90,\text{Au}} = 1337.33 \text{ K}$), or copper ($T_{90,\text{Cu}} = 1357.77 \text{ K}$)§ and in which $L_\lambda(T_{90})$ and $L_\lambda(T_{90,x})$ are the spectral concentrations of the radiance of a blackbody at the wavelength (*in vacuo*) λ at T_{90} and at $T_{90,x}$, respectively, and $c_2 = 0.014388 \text{ m} \cdot \text{K}$. For practical details and good practice for optical pyrometry see reference 3.

§ The T_{90} values of the freezing temperatures of silver, copper, and gold are believed to be self-consistent to such a degree that any one of them in place of one of the other two as the reference temperature $T_{90,x}$ will not result in significant differences in the measured values of T_{90} .

4. Supplementary information and differences from earlier scales

The apparatus, methods, and procedures that will serve to realize the ITS-90 are given in reference 3. That document also gives an account of the earlier International Temperature Scales and the numerical differences between successive scales that include, where practicable, mathematical functions for the differences ($T_{90} - T_{68}$). A number of useful approximations to the ITS-90 are given in reference 4. Those two documents have been prepared by the Comité Consultatif de Thermométrie and are published by the International Bureau of Weights and Measures; they will be revised and updated periodically.

The differences ($T_{90} - T_{68}$) are shown in figure 1 and in table 6. The number of significant figures given in table 6 allows smooth interpolations to be made. However, the reproducibility of the IPTS-68 is, in many areas, substantially worse than is implied by that number.

I am most grateful to Dr T. J. Quinn, Director of the Bureau International des Poids et Mesures, for his advice.

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3. *Supplementary Information for the ITS-90*. International Bureau of Weights and Measures: Pavillon de Breteuil, F-92312 Sèvres, France. **1990** (in the press).
4. *Techniques for Approximating the ITS-90*. International Bureau of Weights and Measures: Pavillon de Breteuil, F-92312 Sèvres, France. **1990** (in the press).

Editorial note

The Editors hope that authors of papers for the *Journal* will adopt the ITS-90 as soon as is reasonably possible.

It is now even more important than it was before for authors to state clearly in every paper just which temperature scale they are using.

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