Standard Guide for Expression of Temperature[1]

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1. Scope

1.1 This guide covers uniform methods for expressing temperature, temperature values, and temperature differences.

1.2 This guide is intended as a supplement to IEEE/ASTM SI-10.

2. Referenced Documents

2.1 *ASTM Standards:*

E 344 Terminology Relating to Thermometry and Hydrometry[2]

IEEE/ASTM SI-10 Standard for Use of the International System of Units (SI): The Modern Metric System[3]

3. Terminology

3.1 *General*—Standard terms used in this guide are defined in Terminology E 344 and in IEEE/ASTM SI-10.

4. Basic Concepts

4.1 Temperature is a fundamental measurable quantity designated by the symbol T or the symbol t (see 5.1). In expressions of dimensions the symbol θ is sometimes used to indicate the dimension temperature.

4.2 A temperature value is expressed in terms of a temperature scale. The complete description consists of a numerical value designating the magnitude, a unit, and, where appropriate, a tolerance or uncertainty. Both the numerical value and unit depend upon the scale.

4.3 A unit of temperature is understood to mean an interval on a temperature scale.

4.4 A temperature difference, interval, or increment is also described by a numerical value designating the magnitude, a unit, and, where appropriate, a tolerance or uncertainty.

5. Temperature Scales

5.1 *Thermodynamic Temperature Scales*:

5.1.1 By international agreement, the theoretical temperature scale to which all temperature values should be ultimately referable is the Kelvin Thermodynamic Temperature Scale (KTTS). A value of temperature expressed on the KTTS is known as a thermodynamic temperature, symbol T.

5.1.2 The unit of thermodynamic temperature is the kelvin, symbol K. The kelvin is a base unit in the International System of Units (SI).

NOTE 1—The symbol for the kelvin is the capital letter K only; the degree sign (°) is not used.

5.1.3 The expression of a value of thermodynamic temperature is written:

$$T = n_k \text{ K} \quad (1)$$

where:
n_k = a numerical value designating the magnitude,
K = the symbol for the unit kelvin.

The magnitude may also be represented by the notation T/K.

5.1.4 A thermodynamic temperature may be expressed as a Celsius temperature. The symbol t is to be used to designate a Celsius temperature, but if this symbol leads to a conflict in notation in a given context, it is acceptable to use the symbol T instead to designate a Celsius temperature.

5.1.5 The unit of Celsius temperature is the degree Celsius, symbol °C. The degree Celsius is a derived SI unit.

NOTE 2—The symbol for the degree Celsius consists of the degree sign (°) followed by the capital letter C. Neither the degree sign nor the letter C alone represents the degree Celsius.

5.1.6 The expression of a value of Celsius temperature is written:

$$t = n_c \,°\text{C} \quad (2)$$

where:
n_c = a numerical value designating the magnitude,
°C = the symbol for the unit degree Celsius.

The magnitude may also be represented by the notation t/°C.

5.1.7 By definition, at any temperature, a temperature increment of one degree Celsius is equal to a temperature increment of one kelvin.

5.1.8 By definition, the Celsius temperature $t = 0$ °C is the same as the thermodynamic temperature $T = 273.15$ K. The relation between numerical values associated with both expressions of a temperature is therefore given by:

$$n_c = n_k - 273.15 \quad (3)$$

where:
$t = n_c$ °C is the same temperature as $T = n_k$ K.

[1] This guide is under the jurisdiction of ASTM Committee E-20 on Temperature Measurement and is the direct responsibility of Subcommittee E20.91 on Editorial and Terminology.

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[2] *Annual Book of ASTM Standards*, Vol 14.03.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

5.2 *Practical Temperature Scales*:

5.2.1 Practical temperature scales have been established by international agreement for the practice of temperature measurement; among them are the International Practical Temperature Scale of 1968, the International Practical Temperature Scale of 1948, and the International Temperature Scale of 1927.[4]

5.2.2 The practical temperature scale now in use, superseding all others, is the International Temperature Scale of 1990.[5] It is defined so that a numerical value of temperature expressed on the scale is close to the numerical value of thermodynamic temperature.

5.2.3 A value of temperature on a practical temperature scale may be expressed either in kelvins or in degrees Celsius using the designations, symbols, and relations given in 5.1.

6. Expression of Values of Temperature

6.1 *Temperature Scale Identification*:

6.1.1 It is important that the temperature scale upon which values of temperature are expressed be identified in a document. When reference to more than one scale is made in a document, or when critical data are presented, scale identification is essential.

6.1.2 Thermodynamic temperatures may be identified as such, or with reference to the KTTS. If values of temperature are expressed on a practical temperature scale, the scale should be identified. The identification may be an abbreviation; for example, the International Temperature Scale of 1990 may be abbreviated ITS-90.

6.1.3 Scale identification may be placed in text, in footnotes, in table headings, or in figures, as appropriate.

6.1.4 A scale may also be identified by a subscript associated with a quantity symbol; for example, T_{Th} and t_{Th} for thermodynamic temperatures and T_{90} and t_{90} for temperature values on ITS-90.

6.2 *Numerical Format*:

6.2.1 Numerical values of temperature should be expressed as decimal numbers.

6.2.2 Except in very special circumstances, exponential format should be avoided.

6.3 *Unit Symbol Format*:

6.3.1 The unit symbol should be separated from the numerical value by a single space. There should be no space between the degree sign and the letter C. Punctuation is not part of the unit symbol; only punctuation required by context or grammar should follow the unit symbol.

6.3.2 In an expression of a range of temperature values, the same unit symbol should be used with each value in the range; for example: "over the temperature range 16 K to 50 K" or "any temperature between 20 °C and 30 °C."

6.3.3 Multiple and submultiple prefixes should not normally be used with the unit for the expression of values of temperature.

6.3.4 When a tolerance or uncertainty is associated with a value of temperature, both the value and the tolerance or uncertainty should be expressed with the same unit. Unit prefixes should not normally be used. The unit symbol should follow each numerical value. For example:

$$t_{90} = 60.0\ ^\circ\mathrm{C} \pm 1.5\ ^\circ\mathrm{C} \tag{4}$$

$$T_{90} = 273.150\ \mathrm{K} \pm 0.001\ \mathrm{K} \tag{5}$$

7. Expression of Temperature Differences, Intervals, and Increments

7.1 Temperature differences, intervals, and increments are normally understood to be expressed with reference to the same temperature scale as are values of temperature, within a given context. Where there is a possibility of misunderstanding, the temperature scale should be explicitly identified.

7.2 A small temperature difference, interval, or increment may be expressed in terms of a submultiple of the appropriate unit of temperature. The use of unit prefixes to indicate submultiples should follow the guidelines in IEEE/ASTM SI-10. The preferred submultiple is 0.001 (prefix "milli," symbol m).

7.3 The magnitude of a temperature increment at a particular temperature is sometimes expressed as a relative fraction or a percentage of the numerical value (on a particular temperature scale) of the temperature. Such usage should be carefully explained so that the expression is meaningful and unambiguous.

7.4 When a tolerance or uncertainty is associated with the magnitude of a temperature difference, interval, or increment, both the magnitude and tolerance or uncertainty should be expressed in the same numerical format and with the same unit. An appropriate unit prefix may be used (see 7.2). The resulting unit symbol should follow each numerical value in the expression. For example:

$$\Delta t = 10.00\ ^\circ\mathrm{C} \pm 0.01\ ^\circ\mathrm{C}\ \text{describes a temperature interval of about}\ 10\ ^\circ\mathrm{C} \tag{6}$$

$$\Delta T = 9.8\ \mathrm{mK} \pm 0.2\ \mathrm{mK}\ \text{describes a temperature interval of about}\ 9.8\ \mathrm{mK} \tag{7}$$

7.5 In the expression of derived quantities the unit of temperature should be the kelvin. For example, the preferred expression for heat capacity is joules per kelvin, $\mathrm{J \cdot K^{-1}}$ or J/K; for temperature gradient, kelvins per metre, $\mathrm{K \cdot m^{-1}}$ or K/m.

8. Units Other Than SI

8.1 Values of temperature are sometimes expressed in degrees Rankine, symbol °R, instead of kelvins, and in degrees Fahrenheit, symbol °F, instead of degrees Celsius. Neither the degree Rankine nor the degree Fahrenheit are part of SI.

8.2 At any temperature, a temperature increment of one degree Rankine is equal to a temperature increment of 5/9 kelvin. The relation between numerical values associated with both expressions of a temperature is given by:

$$n_{\mathrm{r}} = 9n_{\mathrm{k}}/5 \tag{8}$$

where:
$T = n_{\mathrm{r}}$ °R is the same temperature as $T = n_{\mathrm{k}}$ K.

8.3 At any temperature, a temperature increment of one degree Fahrenheit is equal to a temperature increment of 5/9

[4] *Evolution of the International Practical Temperature Scale of 1968, ASTM STP 565*, ASTM, 1974.

[5] Preston-Thomas, H., "The International Temperature Scale of 1990 (ITS-90)," *Metrologia*, Vol 27, No. 1, 1990, pp. 3–10. For errata see *ibid*, Vol 27, No. 2, 1990, p. 107.

degree Celsius. The relation between numerical values associated with both expressions of a temperature is given by:

$$n_f = 9n_c / 5 + 32 \quad (9)$$

where:
t = n_f °F is the same temperature as $t = n_c$°C.

8.4 From the relations in 5.1, 8.2, and 8.3, it follows that:

8.4.1 At any temperature, a temperature increment of one degree Rankine is equal to a temperature increment of one degree Fahrenheit.

8.4.2 If $T = n_r$ °R and $t = n_f$ °F are the same temperature, then the relation between the numerical values is given by:

$$n_r = n_f + 459.67 \quad (10)$$

8.4.3 If a temperature interval expressed in degrees Rankine or degrees Fahrenheit has a magnitude n_1, and the same temperature interval expressed in kelvins or degrees Celsius has a magnitude n_2, then the relation between n_1 and n_2 is given by:

$$n_1 = 9n_2 / 5 \quad (11)$$

8.5 Both thermodynamic temperatures and values of temperature on a practical temperature scale may be expressed in degrees Rankine or degrees Fahrenheit. In both cases the considerations of Section 6 apply.

8.6 The use of multiple and submultiple prefixes with the degree Rankine and the degree Fahrenheit is not recommended.

9. Keywords

9.1 degree Celsius; degree Fahrenheit; degree Rankine; kelvin; SI; temperature; temperature difference; temperature increment; temperature interval; temperature scales; temperature value; thermodynamic temperature