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An American National Standard

Standard Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples[1]

This standard is issued under the fixed designation E 230; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

Note—Paragraph 1.1, and Tables 7, 13, 19, 21, and 46 were editorially corrected and the year date changed on Sept. 23, 2003.

1. Scope

1.1 This specification contains reference tables (Tables 8–25) that give temperature-electromotive force (emf) relationships for Types B, E, J, K, N, R, S, T, and C thermocouples.[2] These are the thermocouple types most commonly used in industry.

1.2 Also included are lists of standard and special tolerances on initial values of emf versus temperature for thermocouples (Table 1), thermocouple extension wires (Table 2), and compensating extension wires for thermocouples (Table 3).

1.3 Tables 4–5, included herein, give data on insulation color coding for thermocouple and thermocouple extension wires as customarily used in the United States.

1.4 Recommendations regarding upper temperature limits for the thermocouple types referred to in 1.1 are given in Table 6.

1.5 Tables 26–45 give temperature-emf data for single-leg thermoelements referenced to platinum (NIST Pt 67). The tables include values for Types BP, BN, JP, JN, KP (same as EP), KN, NP, NN, TP, and TN (same as EN).

1.6 Tables for Types RP, RN, SP, and SN thermoelements are not included since, nominally, Tables 18–21 represent the thermoelectric properties of Type RP and SP thermoelements referenced to pure platinum. Tables for the individual thermoelements of Type C are not included because materials for Type C thermocouples are normally supplied as matched pairs only.

1.7 Polynomial coefficients that may be used for computation of thermocouple emf as a function of temperature are given in Table 7. Coefficients for the emf of each thermocouple pair as well as for the emf of most individual thermoelements versus platinum are included. Coefficients for type RP and SP thermoelements are not included since they are nominally the same as for the types R and S thermocouples, and coefficients for type RN or SN relative to the nominally similar Pt-67 would be insignificant. Coefficients for the individual thermoelements of type C are not established.

1.8 Coefficients for sets of inverse polynomials are given in Table 44. These may be used for computing a close approximation of temperature (°C) as a function of thermocouple emf. Inverse functions are provided only for thermocouple pairs and are valid only over the emf ranges specified.

1.9 This specification is intended to define the thermoelectric properties of materials that conform to the relationships presented in the tables of this standard and bear the letter designations contained herein. Topics such as ordering information, physical and mechanical properties, workmanship, testing, and marking are not addressed in this specification. The user is referred to specific standards such as Specifications E 235, E 574, E 585, E 608, E 1159, or E 1223, as appropriate, for guidance in these areas.

1.10 The temperature-emf data in this specification are intended for industrial and laboratory use.

2. Referenced Documents

2.1 *ASTM Standards:*

E 235 Specification for Thermocouples, Sheathed, Type K, for Nuclear or for Other High-Reliability Applications[3]

E 574 Specification for Duplex, Base-Metal Thermocouple Wire with Glass Fiber or Silica Fiber Insulation[3]

E 585 Specification for Sheathed Base-Metal Thermocouple Materials[3]

E 608 Specification for Metal-Sheathed Base-Metal Thermocouples[3]

E 1159 Specification for Thermocouple Materials, Platinum-Rhodium Alloys, and Platinum[3]

E 1223 Specification for Type N Thermocouple Wire[3]

2.2 *NIST Monograph:*

NIST Monograph 175 Temperature-Electromotive Force Reference Functions and Tables for the Letter-Designated Thermocouple Types Based on the ITS-90[4]

[1] These tables are under the jurisdiction of ASTM Committee E20 on Temperature Measurement and are the direct responsibility of Subcommittee E20.04 on Thermocouples.

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[2] These temperature-emf relationships have been revised as required by the international adoption in 1989 of a revised International Temperature Scale (ITS-90).

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

[4] Available from National Institute of Standards and Technology, U.S. Department of Commerce, Gaithersburg, MD 20899.

2.3 *IEC Standard:*
IEC 584–3 First edition, 1989

3. Source of Data

3.1 The data in these tables are based upon the SI volt[5] and the International Temperature Scale of 1990.

3.2 The temperature-emf data in Tables 8–23 and 26–45, together with the corresponding equations in Tables 7 and 46 for all of the thermocouple types, except type C, have been extracted from NIST Monograph 175. Temperature-emf data in Tables 24–25 and the coefficients for type C in Tables 7 and 46 have been developed from curves fitted to wire manufacturers' data.

NOTE 1—It is beyond the scope of this standard to discuss the origin of these tables, but if further information is desired, the reader should consult the NIST reference noted above.

3.3 These tables give emf values to three decimal places (1 μV) at temperature intervals of one degree. Such tables are satisfactory for most industrial uses but may not be adequate for computer and similar applications. If greater precision is required, the reader should refer to the NIST reference noted above which includes tables giving emf values to four decimal places (0.1 μV) for each type except type C. Equations which permit easy and unique generation of the temperature-emf relationships will be found in Table 7. For convenience, coefficients of inverse polynomials that may be used to compute approximate temperature (°C) as a function of thermocouple emf are given in Table 46.

4. Thermocouple Types and Letter Designations

4.1 The letter symbols identifying each reference table are those which are in common use throughout industry and identify the following thermocouple calibrations:

4.1.1 *Type B*—Platinum-30% rhodium (+) versus platinum-6 % rhodium (−).

4.1.2 *Type E*—Nickel-10 % chromium (+) versus copper-45% nickel (constantan) (−).

4.1.3 *Type J*—Iron (+) versus copper-45% nickel (constantan) (−).

4.1.4 *Type K*—Nickel-10 % chromium (+) versus nickel-5 % (aluminum, silicon) (−) (Note 2).

NOTE 2—Silicon, or aluminum and silicon, may be present in combination with other elements.

4.1.5 *Type N*—Nickel-14 % chromium, 1½ % silicon (+) versus nickel-4½ % silicon-⅒ % magnesium (−).

4.1.6 *Type R*—Platinum-13 % rhodium (+) versus platinum (−).

4.1.7 *Type S*—Platinum-10 % rhodium (+) versus platinum (−).

4.1.8 *Type T*—Copper (+) versus copper-45% nickel (constantan) (−).

4.1.9 *Type C*—Tungsten-5% Rhenium (+) versus Tungsten-26% Rhenium (−).

4.2 Each letter designation of 4.1 identifies a specific temperature-emf relationship (Tables 8–23) and may be applied to any thermocouple conforming thereto within stated tolerances on initial values of emf versus temperature, regardless of its composition.

4.3 The thermoelement identifying symbols in Tables 26 to 45 use the suffix letters P and N to denote, respectively, the positive and negative thermoelement of a given thermocouple type.

4.4 Tables 26 to 45 identify specific temperature-emf relationships of individual thermoelements with respect to platinum (NIST Pt-67). Although tolerances on initial values of emf versus temperature, in most cases, are not established for individual thermoelements with respect to platinum, the appropriate letter designation may be applied to any thermoelement which, when combined with its mating thermoelement, will form a thermocouple conforming to the corresponding table within the stated tolerances.

4.5 An overall suffix letter "X" (for example KX, TX, EPX, JNX) denotes an "extension grade" material whose thermoelectric properties will match those of the corresponding thermocouple type within the stated extension grade tolerances over a limited temperature span. Most base metal extension wires have the same nominal composition as the thermocouple wires with which they are intended to be used, whereas the *compensating* extension wires for noble metal or refractory metal thermocouple types (S, R, B, or C) are usually of a different, more economical composition whose relative thermoelectric properties as a pair nonetheless closely approximate those of the noble metal or refractory metal thermocouples with which they are to be used.

5. Tolerances on Initial Values of EMF versus Temperature

5.1 Thermocouples and matched thermocouple wire pairs are normally supplied to the tolerances on initial values of emf versus temperature listed in Table 1.

5.1.1 Tolerances on initial values of emf versus temperature for single-leg thermoelements referenced to platinum have been established only for Types KP and KN. These are supplied, by common practice, to a tolerance equivalent to one half the millivolt tolerance of the Type K thermocouple.

5.1.2 For all other thermocouple types, tolerances on initial values of emf versus temperature for single thermoelements, when required, should be established by agreement between the consumer and the producer.

5.1.3 In reference Tables 34, 35, 44, and 45, the thermoelements are identified by two thermoelement symbols indicating their applicability to two thermocouple types. This indicates that the temperature-electromotive force relationship of the table is typical of the referenced thermoelements over the temperature range given in Table 1 for the corresponding thermocouple type. It should not be assumed, however, that thermoelements used with one thermocouple type are interchangeable with those of the other, or that they have the same millivolt tolerances for the initial values of emf versus temperature.

[5] Discussed in NIST Technical Note 1263, Guidelines for Implementing the New Representations of the Volt and Ohm Effective January 1, 1990.

5.2 Thermocouple extension wires and compensating extension wires are supplied to the tolerances on initial values of emf versus temperature shown in Tables 2–3.

5.2.1 The initial tolerances of extension grade materials and compensating extension materials apply over a more limited span of temperature than the corresponding thermocouple grade materials. Applicable temperature ranges, consistent with typical usage, are given in Tables 2–3.

6. Color Coding

6.1 Color codes for insulation on thermocouple grade materials, along with corresponding thermocouple and thermoelement letter designations, are given in Table 4.

6.2 Extension wires for thermocouples are distinguished by having an identifying color in the outer jacket as shown in Table 5, where letter designations for the extension thermoelements and pairs are also presented.

6.3 Information in Tables 4–5 is based on customary United States practice.

NOTE 3—Other insulation color coding conventions may be found in use elsewhere in the world.

7. List of Tables

7.1 Following is a list of the tables included in this standard:

7.1.1 *General Tables*:

Table Number	Title
1	Tolerances on Initial Values of Emf versus Temperature for Thermocouples
2	Tolerances on Initial Values of Emf versus Temperature for Extension Wires
3	Tolerances on Initial Values of Emf versus Temperature for Compensating Extension Wires
4	United States Color Codes for Single and Duplex Insulated Thermocouple Wires
5	United States Color Codes for Single and Duplex Insulated Extension Wires
6	Suggested Upper Temperature Limits for Protected Thermocouples
7	Polynomial Coefficients for Generating Thermocouple EMF as a Function of Temperature

7.1.2 *EMF versus Temperature Tables for Thermocouples*:

Table Number	Thermocouple Type	Temperature Range[A]
8	B	0 to 1820°C
9	B	32 to 3308°F
10	E	−270 to 1000°C
11	E	−454 to 1832°F
12	J	−210 to 1200°C
13	J	−346 to 2192°F
14	K	−270 to 1372°C
15	K	−454 to 2500°F
16	N	−270 to 1300°C
17	N	−454 to 2372°F
18	R	−50 to 1768°C
19	R	−58 to 3214°F
20	S	−50 to 1768°C
21	S	−58 to 3214°F
22	T	−270 to 400°C
23	T	−454 to 752°F
24	C	0 to 2315°C
25	C	32 to 4200°F

7.1.3 *EMF versus Temperature Tables for Thermoelements*:

Table Number	Thermocouple Type	Thermoelement Type	Temperature Range[A]
26	B	BP	0 to 1768°C
27	B	BP	32 to 3214°F
28	B	BN	0 to 1768°C
29	B	BN	32 to 3214°F
30	J	JP	−210 to 760°C
31	J	JP	−346 to 1400°F
32	J	JN	−210 to 760°C
33	J	JN	−346 to 1400°F
34	K or E	KP or EP	−270 to 1372°C
35	K or E	KP or EP	−454 to 2500°F
36	K	KN	−270 to 1372°C
37	K	KN	−454 to 2500°F
38	N	NP	−200 to 1300°C
39	N	NP	−328 to 2372°F
40	N	NN	−200 to 1300°C
41	N	NN	−328 to 2372°F
42	T	TP	−270 to 400°C
43	T	TP	−454 to 752°F
44	T or E	TN or EN	−270 to 1000°C
45	T or E	TN or EN	−454 to 1832°F

[A] These temperature ranges represent the range of published temperature versus emf data for the thermocouple and thermoelement types listed. Refer to Table 6 for recommended maximum upper use temperature limits for a specific thermocouple wire size and type.

7.1.4 *Supplementary Table*:

Table Number	Title
46	Coefficients of Inverse Polynomials for Computation of Approximate Temperature as a Function of Thermocouple EMF

8. Keywords

8.1 emf computation; compensating extension wire; inverse polynomial; polynomial coefficient; reference tables; thermocouple; thermocouple extension wire; thermoelement; upper temperature limit