ISA-MC96.1-1982
Approved August 12, 1982

Standard

Temperature Measurement Thermocouples

ISA-MC96.1 — Temperature Measurement Thermocouples

ISBN 0-87664-708-5

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Preface

This Preface is included for information purposes and is not part of ISA-MC96.1.

The development of this standard has resulted from the work of the American National Standards Committee on Temperature Measurement, MC96. The Committee was organized in 1946 under the sponsorship of ISA, the scope of the Committee being designated as follows:

Requirements for temperature measurement thermocouples, including terminology, fabrication, wire sizes, installation, color codes of thermocouple and thermocouple extension wire, temperature-EMF tables and tolerances have been coordinated with the International Electrotechnical Commission (IEC).

Credit must be given to the National Bureau of Standards and to Committee E20 on Temperature Measurement of the American Society for Testing and Materials for the development of the temperature-EMF tables and for recommendations as to the maximum recommended temperature of the various materials. Special credit must also be given to G. W. Burns, NBS-Washington, D.C., and Dr. Robert Powell, formerly with NBS-Boulder, for providing the thermocouple reference tables.

This standard has been prepared as a part of the service of ISA toward a goal of uniformity in the field of instrumentation. To be of real value this document should not be static but should be subjected to periodic review. Toward this end the Society welcomes all comments and criticisms and asks that they be addressed to the Standards and Practices Board Secretary; ISA; P.O. Box 12277; Research Triangle Park, N.C. 27709; Telephone 919-549-8411, e-mail: standards@isa.org.

In 1821, Seebeck discovered that, in a closed circuit made up of wires of two dissimilar metals, electric current will flow if the temperature of one junction is elevated above that of the other. In 1886, Le Chatelier introduced a thermocouple consisting of one wire of platinum and the other of 90 percent platinum-10 percent rhodium. This combination, Type S, is still the international standard for purposes of calibration and comparison, and defines the International Practical Temperature Scale of 1968 from the antimony to the gold point. This type of thermocouple was made and sold by W. C. Heraeus, GmbH of Hanau, Germany, and is sometimes called the Heraeus Couple. Somewhat later, it was learned that a thermoelement composed of 87 percent platinum and 13 percent rhodium, Type R, would give a somewhat higher EMF output. This type is frequently used in industry. In 1954 a thermocouple was introduced in Germany whose positive leg is an alloy of platinum and 30 percent rhodium. Its negative leg is also an alloy of platinum and 6 percent rhodium. This combination, Type B, gives somewhat greater physical strength and greater stability and can withstand somewhat higher temperature than Types R and S.

In an effort to find less costly metals for use in thermocouples, a number of combinations were tried. Iron and nickel were useful and inexpensive. Pure nickel, however, becomes very brittle upon oxidation, and it was learned that an alloy of about 55 percent copper, 45 percent nickel originally known as constantan would eliminate this problem. This alloy combination, iron-constantan, has since been widely used and is designated Type J. The present calibration for Type J was established by the National Bureau of Standards (see NBS Monograph 125).

In an effort to find a couple useful to higher temperatures than the iron versus copper-nickel combination, a 90 percent nickel-10 percent chromium alloy as a positive wire, and a 95 percent nickel-5 percent aluminum, manganese, silicon alloy as a negative wire was developed. This combination (originally called Chromel-Alumel) is known as Type K. Similar alloys for specific applications have since become available, to the same curve.

Another combination, copper versus copper-nickel, Type T, is used particularly at below-zero temperatures. The temperature-EMF Reference Table was prepared by the National Bureau of Standards in 1938 and revised in NBS Monograph 125.

The Type E Thermocouple, 90 percent nickel-10 percent chromium versus copper-nickel, is receiving increasing attention and use where corrosion of small diameter iron wire is a problem and a higher EMF output is desirable.

Further information on the letter designated type thermocouples is given in Appendix C.

Several combinations using tungsten, rhenium and their binary alloys are widely used at high temperatures in inert or reducing atmospheres, and are nearing acceptance as standard.

For additional information on temperature measurement thermocouples, reference may be made to NBS Special Publication 300, Volume II, "Precision Measurement and Calibration-Temperature," 1968 and to NBS Monographs 124 and 125, published by United States Department of Commerce, National Bureau of Standards. Specific attention is called to the reference categories on Thermoelectric Theory and Calibration, and Thermoelectric Devices. Additional information is in STP-470B, "Manual on the Use of Thermocouples," 1981, published by the American Society for Testing and Materials.

For many years, letter designations have been assigned by ANSI Committee MC96 and endorsed by international standards as a device to identify certain common types without using proprietary trade names, and to associate them with temperature-EMF relationships established by the National Bureau of Standards. Color codes for the insulation of letter-designated wires are also assigned by MC96 to facilitate identification in the field. The assignment of a letter designation and/or color code by MC96 constitutes an acknowledgment of an existing recognition by NBS of a defining temperature-EMF relationship and an existing general usage, and does not constitute an endorsement of the thermocouple type by ISA, ANSI, and NBS. The letter designation applies only to the temperature-EMF relationship and not to the material. Other material, having different temperature-EMF relationships, may well be equivalent or superior in some applications.

The use of the letter X to indicate thermocouple extension wire appeared obvious. The use of the term lead wire, or compensating lead wire, is to be discouraged because it frequently is confused with the term lead (element).

Much discussion was involved in the use of the color red to designated polarity, since red is used popularly in electrical circuits to indicate positive. No nationally-accepted code known to the committee covered this point. Research into manufacturers' records showed that, in thermocouple circuits, the red negative had been in use for more than forty years.

The colors used to designate the various compositions and combination of thermocouple and extension wire were originally selected upon an almost arbitrary basis. Colors which had been used by large manufacturers were given very careful consideration and comparison so that as few changes as possible would be required to establish uniformity. Millions of miles of wire with these color codes are presently in use.

In ISA-MC96.1 thermocouple and thermocouple extension wires are designated by letters. This has been done primarily to eliminate the use of proprietary names. The designations are given in Table 1 of the text.

The ISA Standards and Practices Department is aware of the growing need for attention to the metric system of units in general, and the International System of Units (SI) in particular, in the preparation of instrumentation standards. The Department is further aware of the benefits to USA users of ISA Standards of incorporating suitable references to the SI (and the metric system) in their business and professional dealings with other countries. Toward this end this Department will endeavor to introduce SI and SI-acceptable metric units as optional alternatives to English units in all new and revised standards to the greatest extent possible. *The ASTM Metric Practice Guide*, endorsed and published as National Bureau of Standards Handbook 102 and as ANSI Z210.1, is the reference guide for definitions, symbols, abbreviations and conversion factors.

Contents

1 Coding of thermocouple wire and extension wires

This standard applies to thermocouples and extension wires.

Its purpose is to establish uniformity in the designation of thermocouples and extension wires and to provide, by means of the color of its insulation, an identification of its type or composition as well as its polarity when used as part of a thermocouple system.

Table 1 — Thermocouple type letter designations

Type	Nominal Temperature Range	Temperature-EMF Relationship Data	Material Identification* (Positive Material in Caps) **
B	0 to 1820°C	Refer to Table 11	PLATINUM-30 PERCENT RHODIUM versus platinum-6 percent rhodium
E	–270 to 1000°C	Refer to Table 12	NICKEL-10 PERCENT CHROMIUM† versus copper-nickel
J	–210 to 760°C	Refer to Table 13	IRON versus copper-nickel
K	–270 to 1372°C	Refer to Table 14	NICKEL-10 PERCENT CHROMIUM † versus nickel-5 percent (aluminium, silicon) ††
R	–50 to 1768°C	Refer to Table 15	PLATINUM-13 PERCENT RHODIUM versus platinum
S	–50 to 1768°C	Refer to Table 16	PLATINUM-10 PERCENT RHODIUM versus platinum
T	–270 to 400°C	Refer to Table 17	COPPER versus copper-nickel

*Any combination of thermocouple materials having EMF-temperature relationships within the tolerances for any of the above-mentioned tables shall bear that table's appropriate type letter designation.

**The indicated polarity of the thermocouple materials applies for conditions when the measuring junction is at higher temperatures than the reference junction.

†It should not be assumed that thermoelements used with more than one thermocouple type are interchangeable or have the same millivolt limits of error.

††Silicon, or aluminum and silicon may be present in combination with other elements.

Table 2 — Symbols for types of thermocouple wire

	Thermoelements	
Type*	Positive	Negative
B	BP	BN
E	EP	EN
J	JP	JN
K	KP	KN
R	RP	RN
S	SP	SN
T	TP	TN

*Any thermocouple material having temperature-EMF relationships within the tolerances for any of the above-mentioned tables shall bear that table's appropriate "type-letter" designation. Identification of some typical materials is contained in Appendix C (Table C-1).

Table 3 — Symbols for types of extension wire

Type	Combination	Positive	Negative
B	BX**	BPX	BNX
E	EX	EPX	ENX
J	JX	JPX	JNX
K	KX	KPX	KNX
R or S	SX*	SPX	SNX
T	TX	TPX	TNX

*Both Type R or S Thermocouples use the same SX compensating extension wire.
**Special compensating extension wires are not required for reference junction temperatures up to 100 ° C. Generally copper conductors are used. However, proprietary alloys may be obtained for use at higher reference junction temperatures.

NOTE: Identification of some typical materials is contained in Appendix C (Table C-3).

Table 4 — Color code — duplex insulated thermocouple wire

Thermocouple			Color of Insulation		
Type	**Positive**	**Negative**	**Overall***	**Positive***	**Negative**
E	EP	EN	Brown	Purple	Red
J	JP	JN	Brown	White	Red
K	KP	KN	Brown	Yellow	Red
T	TP	TN	Brown	Blue	Red

* A tracer color of the positive wire code color may be used in the overall braid.

Table 5 — Color code — single conductor insulated thermocouple extension wire

Extension Wire Type			Color of Insulation	
Type	**Positive**	**Negative**	**Positive**	**Negative***
B	BPX	BNX	Gray	Red-Gray Trace
E	EPX	ENX	Purple	Red-Purple Trace
J	JPX	JNX	White	Red-White Trace
K	KPX	KNX	Yellow	Red-Yellow Trace
R or S	SPX	SNX	Black	Red-Black Trace
T	TPX	TNX	Blue	Red-Blue Trace

*The color identified as a trace may be applied as a tracer, braid, or by any other readily identifiable means.

NOTE OF CAUTION: In the procurement of random lengths of single conductor insulated extension wire, it must be recognized that such wire is commercially combined in matching pairs to conform to established temperature-EMF curves. Therefore, it is imperative that all single conductor insulated extension wire be procured in pairs, at the same time, and from the same source.

Table 6 — Color code — duplex insulated thermocouple extension wire

Extension Wire Type			Color of Insulation		
Type	Positive	Negative	Overall	Positive	Negative*
B	BPX	BNX	Gray	Gray	Red
E	EPX	ENX	Purple	Purple	Red
J	JPX	JNX	Black	White	Red
K	KPX	KNX	Yellow	Yellow	Red
R or S	SPX	SNX	Green	Black	Red
T	TPX	TNX	Blue	Blue	Red

*A tracer having the color corresponding to the positive wire code color may be used on the negative wire color code.

2 Terminology, wire size, upper temperature limit, and initial calibration tolerance for thermocouples and extension wire

2.1 Scope and purpose

This section applies to thermocouples and extension wire.

This section establishes terminology, symbols, normal wire size, recommended upper temperature limit, and tolerance for thermocouples and extension wire.

2.2 Terminology and symbols

2.2.1 Thermoelement

A thermoelement is one of the two dissimilar electrical conductors comprising a thermocouple.

2.2.2 Thermocouple

A thermocouple is two dissimilar thermoelements so joined as to produce a thermal EMF when the measuring and reference junctions are at different temperatures.

1) *Measuring Junction:* The measuring junction is that junction of a thermocouple which is subjected to the temperature to be measured.

2) *Reference Junction:* The reference junction is that junction of a thermocouple which is at a known temperature or which is automatically compensated for its temperature.

NOTE: In normal industry practice the thermocouple element is terminated at the connection head. However, the Reference Junction is not ordinarily located in the connection head but is transferred to the instrument by the use of thermocouple extension wire.

2.2.3 Extension wire

Extension wire is a pair of wires having such temperature EMF characteristics relative to the thermocouple with which the wires are intended to be used that, when properly connected to the thermocouple, the reference junction is transferred to the other end of the wires.

> **NOTE:** Extension wires which are basically different in chemical composition from the thermocouple wires with which they are to be used are sometimes referred to as compensating extension wire. In this context, type SX and BX wires would be compensating extension wire and types TX, JX, EX, and KX wires would be extension wire.

2.2.4 Tolerances

The tolerance of a thermocouple or extension wire is the maximum allowable deviation in degrees from the standard EMF-temperature values for the type of thermocouple in question when the reference junction temperature is at the ice point and the measuring junction is at the temperature to be measured.

2.2.5 Thermocouple element

A thermocouple element is a pair of bare or insulated thermoelements joined at one end to form a measuring junction and intended for use as a thermocouple or as a part of a thermocouple assembly. (See Figure 1.)

The thermocouple element length is the overall length of the thermocouple element and is assigned the symbol A.

The thermocouple element diameter is the maximum transverse dimension of the insulated portion of the thermocouple element and is assigned the symbol Y.

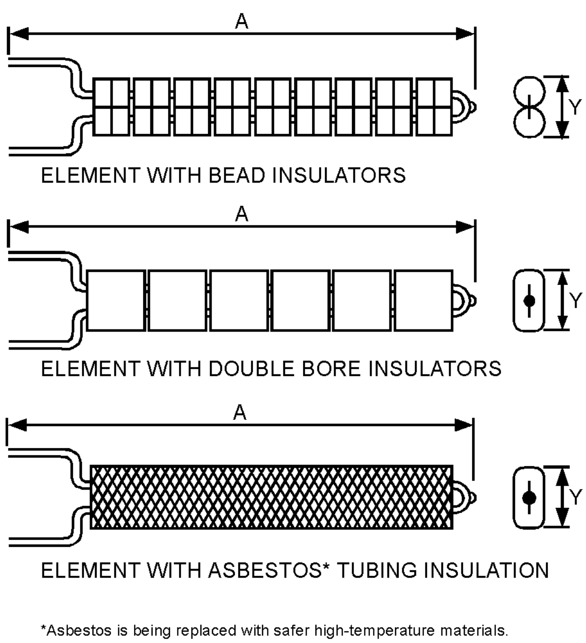

Figure 1 — Thermocouple elements

2.2.6 Thermocouple assembly

A thermocouple assembly is an assembly consisting of a thermocouple element and one or more associated parts such as terminal block, connection head, and protecting tube.

1) *Terminal block:* A terminal block is a block of insulating material that is used to support and join the terminations of conductors. (See Figure 2.)

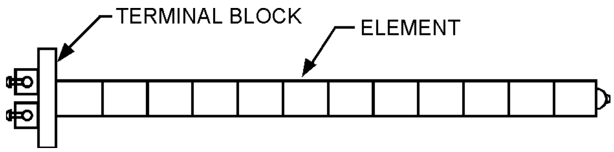

Figure 2 — Thermocouple element with terminal block

2) *Connection head:* A connection head is a housing enclosing a terminal block for an electrical temperature sensing device and usually provided with threaded openings for attachment to a protecting tube and for attachment of conduit. (See Figures 3 and 4.)

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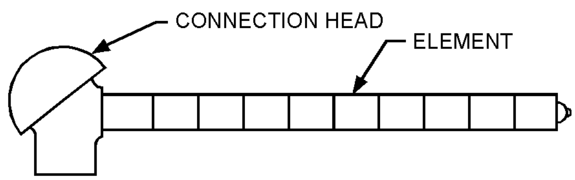

Figure 3 — Thermocouple element with connection head

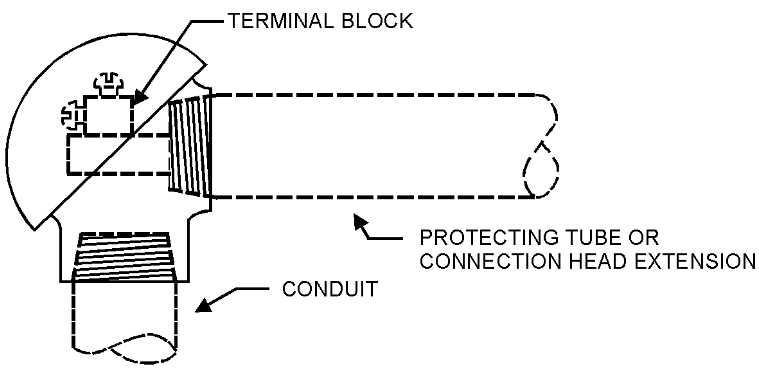

Figure 4 — Connection head

3) *Connection head extension:* A connection head extension is a threaded fitting or an assembly of fittings extending between the thermowell or angle fitting and the connection head.

   The connection head extension length is the overall length of the connection head extension and is assigned the symbol N. (See Figure 11.)

4) *Protecting tube:* A protecting tube is a tube designed to enclose a temperature sensing device and protect it from the deleterious effects of the environment. It may provide for attachment to a connection head but is not primarily designed for pressure-tight attachment to a vessel. A bushing or flange may be provided for the attachment of a protecting tube to a vessel. (See Figures 5, 6, 7, and 8.)

The protecting tube length is the overall length of a protecting tube and is assigned the symbol P. (See Figure 5.)

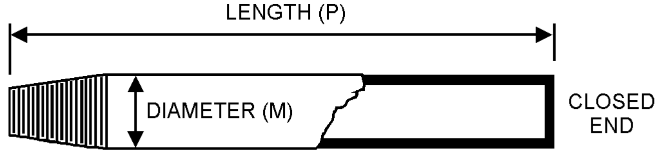

Figure 5 — Protecting tube

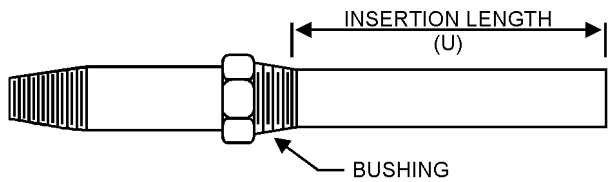

Figure 6 — Protecting tube with mounting bushing

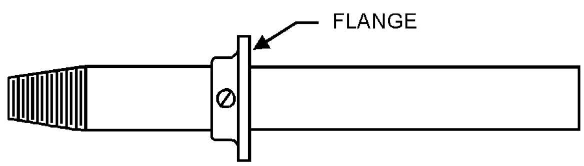

Figure 7 — Protecting tube with mounting flange

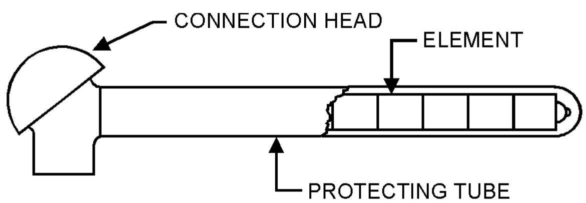

Figure 8 — Thermocouple element with protecting tube and connection head

The protecting tube diameter is the outside diameter of a protecting tube and is assigned the symbol M.

A protecting tube has one end closed unless it is specified as open end. (See Figure 9.)

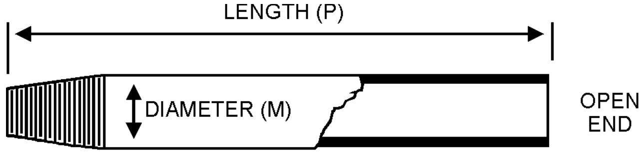

Figure 9 — Open end protecting tube

5) *Thermowell:* A thermowell is a pressure-tight receptacle adapted to receive a temperature sensing element and provided with external threads or other means for pressure-tight attachment to a vessel.

A lagging extension is that portion of a thermowell above the threads, intended to extend through the lagging of a vessel. The lagging extension length is the length from the lower end of the external threads of the well to the outer end of the portion intended to extend through the lagging of a vessel, less one inch allowance for threads, and is assigned the symbol T. (See Figure10.)

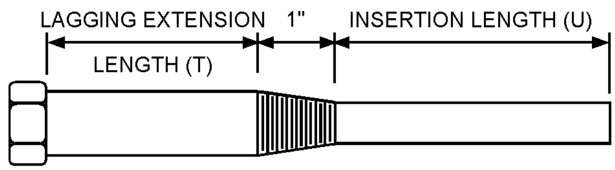

Figure 10 — Well

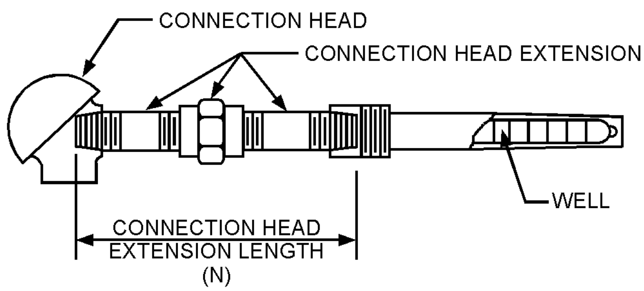

Figure 11 — Thermocouple assembly with thermowell

The immersion length of a thermowell, protecting tube, or thermocouple element is the length from the free end to the point of immersion in the medium which is being measured and is assigned the symbol R. (See Figure 12.)

The insertion length of a thermowell, protecting tube or thermocouple element is the length from the free end to, but not including, the external threads or other means of attachment to a vessel and is assigned the symbol U. (See Figures 10 and 12.)

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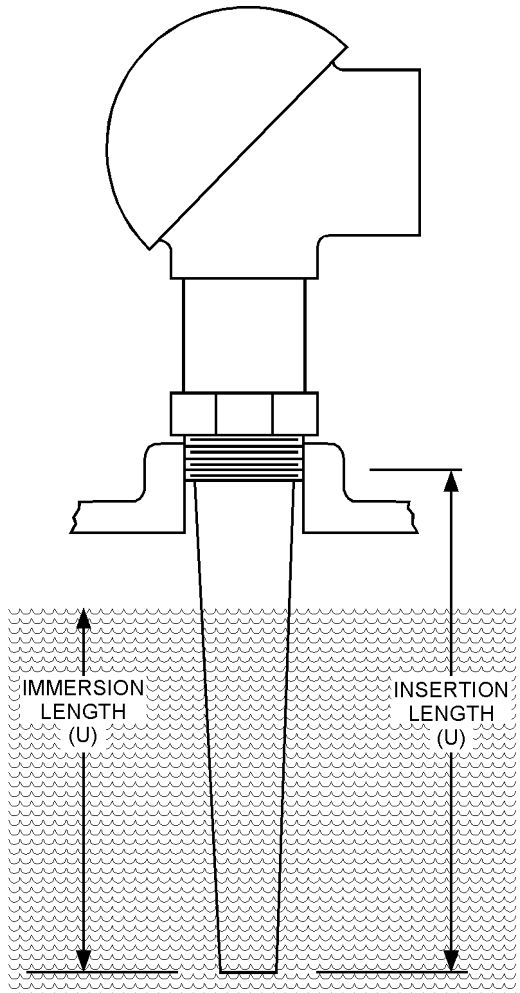

Figure 12 — Immersion and insertion lengths for thermocouple assembly with thermowell

2.2.7 Angle type thermocouple assembly

An angle type thermocouple assembly is an assembly consisting of a thermocouple element, a protecting tube, an angle fitting, a connection head extension, and a connection head.

2.2.8 Other forms of thermocouples and thermocouple elements

1) *Coaxial thermocouple element:* A coaxial thermocouple element consists of a thermoelement in wire form within a thermoelement in tube form and electrically insulated from the tube except at the measuring junction.

2) *Sheathed thermocouple:* A sheathed thermocouple is a thermocouple having its thermoelements, and sometimes its measuring junction, embedded in mineral oxide insulation compacted within a metal protecting tube.

Symbols

	Symbols
Thermocouple element length	A
Thermocouple element diameter	Y
Connection head extension length	N
Protecting tube length	P
Protecting tube diameter	M
Lagging extension length	T
Immersion length	R
Insertion length	U

2.3 Wire sizes

2.3.1 Thermocouples

The wire sizes normally used for non-sheathed thermocouples are as follows:

For J, K, and E: 8, 14, 20, 24, and 28 AWG*

For T: 14, 20, 24, and 28 AWG*

For R, S and B: 24 AWG* only

2.3.2 Extension wires

The wire sizes normally used for extension wire, either singly or in pairs, are 14, 16, and 20 AWG*. Sixteen (16) gage is most commonly used. Twenty (20) gage and smaller may be used when bundled and reinforced to provide strength for pulling. These sizes apply to all types of extension wires.

2.4 Upper temperature limits

Table 7 gives the recommended upper temperature limits for the various thermocouples and wire sizes. These limits apply to protected thermocouples in conventional closed-end protecting tubes. They do not apply to sheathed thermocouples having compacted mineral oxide insulation.

In any general recommendation of thermocouple temperature limits, it is not practical to take into account special cases. In actual operation, there may be instances where the temperature limits recommended can be exceeded. Likewise, there may be applications where satisfactory life will not be obtained at the recommended temperature limits. However, in general, the temperature limits listed are such as to provide satisfactory thermocouple life when the wires are operated continuously at these temperatures. Various factors affecting thermocouple life are discussed in Appendix C.

*American Wire Gage, also known as B&S (Brown & Sharpe)

Table 7 — Recommended upper temperature limits for protected thermocouples. Upper temperature limit for various wire sizes (AWG), Deg C

Thermocouple Type	No. 8 Gage	No. 14 Gage	No. 20 Gage	No. 24 Gage	No. 28 Gage
B				1700	
E	870	650	540	430	430
J	760	590	480	370	370
K	1260	1090	980	870	870
R & S				1480	
T		370	260	200	200

2.5 Tolerance of initial calibration

Tables 8, 9 and 10 give the standard and special tolerance of initial calibration for thermocouples and thermocouple extension wires. The tolerance of initial calibration is defined as the allowable deviation of the thermocouple and extension wire in its initial condition as supplied by the manufacturer from the standard EMF-temperature tables. Once the thermocouple is in use its calibration will change. The magnitude and direction of the change are dependent on temperature, time and environmental conditions affecting the thermocouple and may not be accurately predicted. The tolerances for each type of thermocouple apply only over the temperature range for which the wire size in question is recommended (see Table 7). These tolerances should be applied only to standard wire sizes. The same tolerances may not be obtainable in special sizes. These tolerances do not include installation or system errors. See Appendix C, paragraph C4.1 for the thermocouple installations and errors.

Where tolerances are given in percent, in Table 8, the percentage applies to the temperature being measured. For example, the standard tolerance of Type J over the temperature range 277° to 760°C is ±3/4 percent. If the temperature being measured is 538°C, the tolerance is ±3/4 percent of 538, or ±4.0°C. To determine the tolerance in degrees Fahrenheit, multiply the tolerance in degrees Celsius times 1.8.

Table 8 — Initial calibration tolerances for thermocouples

Reference Junction 0°C			
		TOLERANCES	
Thermocouple Type	**Temperature Range, °C**	**Standard (whichever is greater)**	**Special (whichever is greater)**
B	870 to 1700	±0.5%	
E	0 to 900	± 1.7°C or ±0.5%	±1°C or ±0.4%
J	0 to 750	±2.2°C or ±0.75%	±1.1°C or ±0.4%
K	0 to 1250	±2.2°C or ±0.75%	±1.1°C or ±0.4%
R or S	0 to 1450	±1.5°C or ±0.25%	±0.6°C or ±0.1%
T	0 to 350	±1°C or ±0.75%	±0.5°C or ±0.4%
	Cryogenic Ranges		
E*	–200 to 0	±1.7°C or ±1%	**
K*	–200 to 0	±2.2°C or ±2%	**
T*	– 200 to 0	±1°C or ±1.5%	**

*Thermocouples and thermocouple material are normally supplied to meet the tolerances specified in the table for the normal specified range. The same materials, however, may not fall within the cryogenic tolerances in the second section of the table. If materials are required to meet the cryogenic tolerances, the purchase order must so state. Selection of materials usually will be required. Tolerances indicated in this table are not necessarily an indication of the accuracy of temperature measurements in use after initial heating of the materials.

**Little information is available to justify establishing special tolerances for cryogenic temperatures. Limited experience suggests the following tolerances for Types E and T thermocouples:

Type E –200 to 0°C ±1°C or ±0.5% (whichever is greater)

Type T –200 to 0°C ±0.5°C or ±0.8% (whichever is greater)

These tolerances are given only as guide for discussion between purchaser and supplier. Due to the characteristics of the materials, cryogenic tolerances for Type J thermocouples and special cryogenic tolerances for Type K thermocouples are not listed.

Table 9 — Initial calibration tolerances for thermocouple extension wires

Reference Junction 0°C			
		Tolerances	
Extension Wire Type	**Temperature Range, °C**	**Standard**	**Special**
EX	0 to 200°C	±1.7°C	-
JX	0 to 200°C	±2.2°C	±1.1°C
KX	0 to 200°C	±2.2°C	-
TX	0 to 100°C	±1.0°C	±0.5°C

3 Non-ceramic insulation of thermocouple and extension wires

The normal function of thermocouple and extension wire insulation is to provide electrical insulation. If this function is not provided or is compromised in any way, the indicated temperature may be in error. Insulation of this type (non-ceramic) may be affected adversely by moisture, abrasion, flexing, temperature extremes, chemical attack, and nuclear radiation. Each type of insulation has its own limitations. A knowledge of these limitations is essential if accurate and reliable measurements are to be made.

A number of coatings are presently available commercially. The strong points as well as limitations are discussed in ASTM Special Technical Publication STP-470B, "Manual on the Use of Thermocouples in Temperature Measurement."

In summary, this type of insulation should be selected only after considering possible exposure temperatures and heating rates, the number of temperature cycles, mechanical movement, moisture, routing of the insulated wire, and chemical deterioration.

Table 10 — Initial calibration tolerances for thermocouple compensating extension wire

Reference Junction 0°C			
Thermocouple Type	**Compensating Wire Type**	**Temperature Range, °C**	**Tolerances**
B	BX***	0 to 100	{+0.000 mV (+0°C)*; –0.033 mV (-3.7°C)*}
R, S	SX**	0 to 200	± .057 mV (±5°C)*

*Due to the non-linearity of the Types, R, S, and B temperature-EMF curves, the error introduced into a thermocouple system by the compensating wire will be variable when expressed in degrees. The degree C tolerances given in parentheses are based on the following measuring junction temperatures:

Type Wire	Measuring Junction Temperature
BX	Greater than 1000°C
SX	Greater than 870°C

**Copper (+) versus copper nickel alloy (–).

***Copper versus copper compensating extension wire, usable to 100°C with maximum errors as indicated, but with no significant error over 0 to 50°C range. Matched proprietary alloy compensating wire is available for use over the range 0 to 200°C with claimed tolerances of ±0.033 mV. (±3.7°C*).

4 Temperature-EMF tables for thermocouples

4.1 Scope and purpose

This section applies to the temperature-EMF relationships of materials used for temperature measurement thermocouples.

Its purpose is to provide reference tables of temperature-EMF values for Type B, E, J, K, R, S, and T thermocouples, in a form convenient for industrial and laboratory use.

4.2 Introduction

The values in these tables are based upon the International Practical Temperature Scale of 1968 (IPTS-68) and the U.S. legal electrical units. All the data in Tables 11 to 17 have been extracted from "Thermocouple Reference Tables Based on the IPTS-68," National Bureau of Standards Monograph 125. These tables differ slightly from previous tables for the following reasons: improved measurements and data analysis techniques, slight changes in commercial thermocouple materials, and also changes in the temperature scale and electrical units. The significance of these factors, as well as the origin of each of the tables, is discussed in the NBS reference noted above, and it should be consulted for details.

These tables give values of EMF to three decimal places (0.001 mV) for one degree Celsius (°C) temperature intervals. If greater precision is required, the NBS reference noted above should be consulted. It includes tables giving values of EMF to four decimal places (0.0001 mV) and analytical functions for each thermocouple type that allow a direct and precise calculation of the EMF-temperature relationship.

Tables for each type of thermocouple giving values of EMF as a function of temperature in degrees Fahrenheit (°F) can be found in ANSI/ASTM Standard E230, "Temperature-Electromotive Force (EMF) Tables for Thermocouples." Tables giving EMF-temperature values (in both °C and °F) for single-leg thermoelements referenced to platinum (NBS Pt-67) are also given in the above ANSI/ASTM standard.

4.3 Use of temperature-EMF tables

These temperature-EMF reference tables serve two very useful purposes in that they provide a means for converting the generated EMF of certain thermocouple material combinations into equivalent temperatures, and they enable the calibration and checking of thermocouples and thermocouple extension wire.

If the reference junction is maintained at 0°C, the appropriate temperature or EMF data may be read directly from the tables. When it is not practical to maintain the reference junction temperature at 0°C, these tables may still be used by applying an appropriate correction. The value of the correction may be obtained from these tables. An example to illustrate how to obtain and apply this correction follows.

Let us suppose a Type J thermocouple was used in an installation to determine the temperature of a fluid medium and an EMF output of 18.070 mV was observed. Also, a mercury thermometer in close proximity to the thermocouple reference junction produced a reading of 20°C.

To use the Type J Table to obtain a value for the temperature of the fluid medium, the observed EMF output of the thermocouple must first be corrected to compensate for the difference between the reference junction temperature actually used and 0°C. The correction is the EMF value given by the Type J Table at the reference junction temperature actually used (20°C). As shown below, this EMF value (1.019 mV) is algebraically added to the observed EMF output to obtain the value of EMF that the thermocouple would produce if the reference junction were at 0°C.

Observed Type J Thermocouple Output:	18.070 mV
Correction Factor (Table value at reference temperature actually used) for reference junction at 20°C:	1.019 mV
Corrected Output:	19.089 mV

The corrected output of 19.089 mV is then used to determine from the Type J Table the equivalent temperature value of 350°C.

Table 11 — Temperature-EMF for type B thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
						THERMOELECTRIC VOLTAGE IN MILLIVOLTS						
0	0.000	–0.000	–0.000	–0.001	–0.001	–0.001	–0.001	–0.001	–0.002	–0.002	–0.002	0
10	–0.002	–0.002	–0.002	–0.002	–0.002	–0.002	–0.002	–0.002	–0.003	–0.003	–0.003	10
20	–0.003	–0.003	–0.003	–0.003	–0.003	–0.002	–0.002	–0.002	–0.002	–0.002	–0.002	20
30	–0.002	–0.002	–0.002	–0.002	–0.002	–0.001	–0.001	–0.001	–0.001	–0.001	–0.000	30
40	–0.000	–0.000	–0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.002	40
50	0.002	0.003	0.003	0.003	0.004	0.004	0.004	0.005	0.005	0.006	0.006	50
60	0.006	0.007	0.007	0.008	0.008	0.009	0.009	0.010	0.010	0.011	0.011	60
70	0.011	0.012	0.012	0.013	0.014	0.014	0.015	0.015	0.016	0.017	0.017	70
80	0.017	0.018	0.019	0.020	0.020	0.021	0.022	0.022	0.023	0.024	0.025	80
90	0.025	0.026	0.026	0.027	0.028	0.029	0.030	0.031	0.031	0.032	0.033	90
100	0.033	0.034	0.035	0.036	0.037	0.038	0.039	0.040	0.041	0.042	0.043	100
110	0.043	0.044	0.045	0.046	0.047	0.048	0.049	0.050	0.051	0.052	0.053	110
120	0.053	0.055	0.056	0.057	0.058	0.059	0.060	0.062	0.063	0.064	0.065	120
130	0.065	0.066	0.068	0.069	0.070	0.071	0.073	0.074	0.075	0.077	0.078	130
140	0.078	0.079	0.081	0.082	0.083	0.085	0.086	0.088	0.089	0.091	0.092	140
150	0.092	0.093	0.095	0.096	0.098	0.099	0.101	0.102	0.104	0.106	0.107	150
160	0.107	0.109	0.110	0.112	0.113	0.115	0.117	0.118	0.120	0.122	0.123	160
170	0.123	0.125	0.127	0.128	0.130	0.132	0.133	0.135	0.137	0.139	0.140	170
180	0.140	0.142	0.144	0.146	0.148	0.149	0.151	0.153	0.155	0.157	0.159	180
190	0.159	0.161	0.163	0.164	0.166	0.168	0.170	0.172	0.174	0.176	0.178	190
200	0.178	0.180	0.182	0.184	0.186	0.188	0.190	0.192	0.194	0.197	0.199	200
210	0.199	0.201	0.203	0.205	0.207	0.209	0.211	0.214	0.216	0.218	0.220	210
220	0.220	0.222	0.225	0.227	0.229	0.231	0.234	0.236	0.238	0.240	0.243	220
230	0.243	0.245	0.247	0.250	0.252	0.254	0.257	0.259	0.262	0.264	0.266	230
240	0.266	0.269	0.271	0.274	0.276	0.279	0.281	0.284	0.286	0.289	0.291	240
250	0.291	0.294	0.296	0.299	0.301	0.304	0.307	0.309	0.312	0.314	0.317	250
260	0.317	0.320	0.322	0.325	0.328	0.330	0.333	0.336	0.338	0.341	0.344	260
270	0.344	0.347	0.349	0.352	0.355	0.358	0.360	0.363	0.366	0.369	0.372	270
280	0.372	0.375	0.377	0.380	0.383	0.386	0.389	0.392	0.395	0.398	0.401	280
290	0.401	0.404	0.406	0.409	0.412	0.415	0.418	0.421	0.424	0.427	0.431	290
300	0.431	0.434	0.437	0.440	0.443	0.446	0.449	0.452	0.455	0.458	0.462	300
310	0.462	0.465	0.468	0.471	0.474	0.477	0.481	0.484	0.487	0.490	0.494	310
320	0.494	0.497	0.500	0.503	0.507	0.510	0.513	0.517	0.520	0.523	0.527	320
330	0.527	0.530	0.533	0.537	0.540	0.544	0.547	0.550	0.554	0.557	0.561	330
340	0.561	0.564	0.568	0.571	0.575	0.578	0.582	0.585	0.589	0.592	0.596	340
350	0.596	0.599	0.603	0.606	0.610	0.614	0.617	0.621	0.625	0.628	0.632	350
360	0.632	0.636	0.639	0.643	0.647	0.650	0.654	0.658	0.661	0.665	0.669	360
370	0.669	0.673	0.677	0.680	0.684	0.688	0.692	0.696	0.699	0.703	0.707	370
380	0.707	0.711	0.715	0.719	0.723	0.727	0.730	0.734	0.738	0.742	0.746	380
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 11 (continued) — Temperature-EMF for type B thermocouples
Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
					THERMOELECTRIC VOLTAGE IN MILLIVOLTS							
390	0.746	0.750	0.754	0.758	0.762	0.766	0.770	0.774	0.778	0.782	0.786	390
400	0.786	0.790	0.794	0.799	0.803	0.807	0.811	0.815	0.819	0.823	0.827	400
410	0.827	0.832	0.836	0.840	0.844	0.848	0.853	0.857	0.861	0.865	0.870	410
420	0.870	0.874	0.878	0.882	0.887	0.891	0.895	0.900	0.904	0.908	0.913	420
430	0.913	0.917	0.921	0.926	0.930	0.935	0.939	0.943	0.948	0.952	0.957	430
440	0.957	0.961	0.966	0.970	0.975	0.979	0.984	0.988	0.993	0.997	1.002	440
450	1.002	1.006	1.011	1.015	1.020	1.025	1.029	1.034	1.039	1.043	1.048	450
460	1.048	1.052	1.057	1.062	1.066	1.071	1.076	1.081	1.085	1.090	1.095	460
470	1.095	1.100	1.104	1.109	1.114	1.119	1.123	1.128	1.133	1.138	1.143	470
480	1.143	1.148	1.152	1.157	1.162	1.167	1.172	1.177	1.182	1.187	1.192	480
490	1.192	1.197	1.202	1.206	1.211	1.216	1.221	1.226	1.231	1.236	1.241	490
500	1.241	1.246	1.252	1.257	1.262	1.267	1.272	1.277	1.282	1.287	1.292	500
510	1.292	1.297	1.303	1.308	1.313	1.318	1.323	1.328	1.334	1.339	1.344	510
520	1.344	1.349	1.354	1.360	1.365	1.370	1.375	1.381	1.386	1.391	1.397	520
530	1.397	1.402	1.407	1.413	1.418	1.423	1.429	1.434	1.439	1.445	1.450	530
540	1.450	1.456	1.461	1.467	1.472	1.477	1.483	1.488	1.494	1.499	1.505	540
550	1.505	1.510	1.516	1.521	1.527	1.532	1.538	1.544	1.549	1.555	1.560	550
560	1.560	1.566	1.571	1.577	1.583	1.588	1.594	1.600	1.605	1.611	1.617	560
570	1.617	1.622	1.628	1.634	1.639	1.645	1.651	1.657	1.662	1.668	1.674	570
580	1.674	1.680	1.685	1.691	1.697	1.703	1.709	1.715	1.720	1.726	1.732	580
590	1.732	1.738	1.744	1.750	1.756	1.762	1.767	1.773	1.779	1.785	1.791	590
600	1.791	1.797	1.803	1.809	1.815	1.821	1.827	1.833	1.839	1.845	1.851	600
610	1.851	1.857	1.863	1.869	1.875	1.882	1.888	1.894	1.900	1.906	1.912	610
620	1.912	1.918	1.924	1.931	1.937	1.943	1.949	1.955	1.961	1.968	1.974	620
630	1.974	1.980	1.986	1.993	1.999	2.005	2.011	2.018	2.024	2.030	2.036	630
640	2.036	2.043	2.049	2.055	2.062	2.068	2.074	2.081	2.087	2.094	2.100	640
650	2.100	2.106	2.113	2.119	2.126	2.132	2.139	2.145	2.151	2.158	2.164	650
660	2.164	2.171	2.177	2.184	2.190	2.197	2.203	2.210	2.216	2.223	2.230	660
670	2.230	2.236	2.243	2.249	2.256	2.263	2.269	2.276	2.282	2.289	2.296	670
680	2.296	2.302	2.309	2.316	2.322	2.329	2.336	2.343	2.349	2.356	2.363	680
690	2.363	2.369	2.376	2.383	2.390	2.396	2.403	2.410	2.417	2.424	2.430	690
700	2.430	2.437	2.444	2.451	2.458	2.465	2.472	2.478	2.485	2.492	2.499	700
710	2.499	2.506	2.513	2.520	2.527	2.534	2.541	2.548	2.555	2.562	2.569	710
720	2.569	2.576	2.583	2.590	2.597	2.604	2.611	2.618	2.625	2.632	2.639	720
730	2.639	2.646	2.653	2.660	2.667	2.674	2.682	2.689	2.696	2.703	2.710	730
740	2.710	2.717	2.724	2.732	2.739	2.746	2.753	2.760	2.768	2.775	2.782	740
750	2.782	2.789	2.797	2.804	2.811	2.818	2.826	2.833	2.840	2.848	2.855	750
760	2.855	2.862	2.869	2.877	2.884	2.892	2.899	2.906	2.914	2.921	2.928	760
770	2.928	2.936	2.943	2.951	2.958	2.966	2.973	2.980	2.988	2.995	3.003	770
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 11 (continued) — Temperature-EMF for type B thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
						THERMOELECTRIC VOLTAGE IN MILLIVOLTS						
780	3.003	3.010	3.018	3.025	3.033	3.040	3.048	3.055	3.063	3.070	3.078	780
790	3.078	3.086	3.093	3.101	3.108	3.116	3.124	3.131	3.139	3.146	3.154	790
800	3.154	3.162	3.169	3.177	3.185	3.192	3.200	3.208	3.215	3.223	3.231	800
810	3.231	3.239	3.246	3.254	3.262	3.269	3.277	3.285	3.293	3.301	3.308	810
820	3.308	3.316	3.324	3.332	3.340	3.347	3.355	3.363	3.371	3.379	3.387	820
830	3.387	3.395	3.402	3.410	3.418	3.426	3.434	3.442	3.450	3.458	3.466	830
840	3.466	3.474	3.482	3.490	3.498	3.506	3.514	3.522	3.530	3.538	3.546	840
850	3.546	3.554	3.562	3.570	3.578	3.586	3.594	3.602	3.610	3.618	3.626	850
860	3.626	3.634	3.643	3.651	3.659	3.667	3.675	3.683	3.691	3.700	3.708	860
870	3.708	3.716	3.724	3.732	3.741	3.749	3.757	3.765	3.773	3.782	3.790	870
880	3.790	3.798	3.806	3.815	3.823	3.831	3.840	3.848	3.856	3.865	3.873	880
890	3.873	3.881	3.890	3.898	3.906	3.915	3.923	3.931	3.940	3.948	3.957	890
900	3.957	3.965	3.973	3.982	3.990	3.999	4.007	4.016	4.024	4.032	4.041	900
910	4.041	4.049	4.058	4.066	4.075	4.083	4.092	4.100	4.109	4.117	4.126	910
920	4.126	4.135	4.143	4.152	4.160	4.169	4.177	4.186	4.195	4.203	4.212	920
930	4.212	4.220	4.229	4.238	4.246	4.255	4.264	4.272	4.281	4.290	4.298	930
940	4.298	4.307	4.316	4.325	4.333	4.342	4.351	4.359	4.368	4.377	4.386	940
950	4.386	4.394	4.403	4.412	4.421	4.430	4.438	4.447	4.456	4.465	4.474	950
960	4.474	4.483	4.491	4.500	4.509	4.518	4.527	4.536	4.545	4.553	4.562	960
970	4.562	4.571	4.580	4.589	4.598	4.607	4.616	4.625	4.634	4.643	4.652	970
980	4.652	4.661	4.670	4.679	4.688	4.697	4.706	4.715	4.724	4.733	4.742	980
990	4.742	4.751	4.760	4.769	4.778	4.787	4.796	4.805	4.814	4.824	4.833	990
1000	4.833	4.842	4.851	4.860	4.869	4.878	4.887	4.897	4.906	4.915	4.924	1000
1010	4.924	4.933	4.942	4.952	4.961	4.970	4.979	4.989	4.998	5.007	5.016	1010
1020	5.016	5.025	5.035	5.044	5.053	5.063	5.072	5.081	5.090	5.100	5.109	1020
1030	5.109	5.118	5.128	5.137	5.146	5.156	5.165	5.174	5.184	5.193	5.202	1030
1040	5.202	5.212	5.221	5.231	5.240	5.249	5.259	5.268	5.278	5.287	5.297	1040
1050	5.297	5.306	5.316	5.325	5.334	5.344	5.353	5.363	5.372	5.382	5.391	1050
1060	5.391	5.401	5.410	5.420	5.429	5.439	5.449	5.458	5.468	5.477	5.487	1060
1070	5.487	5.496	5.506	5.516	5.525	5.535	5.544	5.554	5.564	5.573	5.583	1070
1080	5.583	5.593	5.602	5.612	5.621	5.631	5.641	5.651	5.660	5.670	5.680	1080
1090	5.680	5.689	5.699	5.709	5.718	5.728	5.738	5.748	5.757	5.767	5.777	1090
1100	5.777	5.787	5.796	5.806	5.816	5.826	5.836	5.845	5.855	5.865	5.875	1100
1110	5.875	5.885	5.895	5.904	5.914	5.924	5.934	5.944	5.954	5.964	5.973	1110
1120	5.973	5.983	5.993	6.003	6.013	6.023	6.033	6.043	6.053	6.063	6.073	1120
1130	6.073	6.083	6.093	6.102	6.112	6.122	6.132	6.142	6.152	6.162	6.172	1130
1140	6.172	6.182	6.192	6.202	6.212	6.223	6.233	6.243	6.253	6.263	6.273	1140
1150	6.273	6.283	6.293	6.303	6.313	6.323	6.333	6.343	6.353	6.364	6.374	1150
1160	6.374	6.384	6.394	6.404	6.414	6.424	6.435	6.445	6.455	6.465	6.475	1160
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 11 (continued) — Temperature-EMF for type B thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
						THERMOELECTRIC VOLTAGE IN MILLIVOLTS						
1170	6.475	6.485	6.496	6.506	6.516	6.526	6.536	6.547	6.557	6.567	6.577	1170
1180	6.577	6.588	6.598	6.608	6.618	6.629	6.639	6.649	6.659	6.670	6.680	1180
1190	6.680	6.690	6.701	6.711	6.721	6.732	6.742	6.752	6.763	6.773	6.783	1190
1200	6.783	6.794	6.804	6.814	6.825	6.835	6.846	6.856	6.866	6.877	6.887	1200
1210	6.887	6.898	6.908	6.918	6.929	6.939	6.950	6.960	6.971	6.981	6.991	1210
1220	6.991	7.002	7.012	7.023	7.033	7.044	7.054	7.065	7.075	7.086	7.096	1220
1230	7.096	7.107	7.117	7.128	7.138	7.149	7.159	7.170	7.181	7.191	7.202	1230
1240	7.202	7.212	7.223	7.233	7.244	7.255	7.265	7.276	7.286	7.297	7.308	1240
1250	7.308	7.318	7.329	7.339	7.350	7.361	7.371	7.382	7.393	7.403	7.414	1250
1260	7.414	7.425	7.435	7.446	7.457	7.467	7.478	7.489	7.500	7.510	7.521	1260
1270	7.521	7.532	7.542	7.553	7.564	7.575	7.585	7.596	7.607	7.618	7.628	1270
1280	7.628	7.639	7.650	7.661	7.671	7.682	7.693	7.704	7.715	7.725	7.736	1280
1290	7.736	7.747	7.758	7.769	7.780	7.790	7.801	7.812	7.823	7.834	7.845	1290
1300	7.845	7.855	7.866	7.877	7.888	7.899	7.910	7.921	7.932	7.943	7.953	1300
1310	7.953	7.964	7.975	7.986	7.997	8.008	8.019	8.030	8.041	8.052	8.063	1310
1320	8.063	8.074	8.085	8.096	8.107	8.118	8.128	8.139	8.150	8.161	8.172	1320
1330	8.172	8.183	8.194	8.205	8.216	8.227	8.238	8.249	8.261	8.272	8.283	1330
1340	8.283	8.294	8.305	8.316	8.327	8.338	8.349	8.360	8.371	8.382	8.393	1340
1350	8.393	8.404	8.415	8.426	8.437	8.449	8.460	8.471	8.482	8.493	8.504	1350
1360	8.504	8.515	8.526	8.538	8.549	8.560	8.571	8.582	8.593	8.604	8.616	1360
1370	8.616	8.627	8.638	8.649	8.660	8.671	8.683	8.694	8.705	8.716	8.727	1370
1380	8.727	8.738	8.750	8.761	8.772	8.783	8.795	8.806	8.817	8.828	8.839	1380
1390	8.839	8.851	8.862	8.873	8.884	8.896	8.907	8.918	8.929	8.941	8.952	1390
1400	8.952	8.963	8.974	8.986	8.997	9.008	9.020	9.031	9.042	9.053	9.065	1400
1410	9.065	9.076	9.087	9.099	9.110	9.121	9.133	9.144	9.155	9.167	9.178	1410
1420	9.178	9.189	9.201	9.212	9.223	9.235	9.246	9.257	9.269	9.280	9.291	1420
1430	9.291	9.303	9.314	9.326	9.337	9.348	9.360	9.371	9.382	9.394	9.405	1430
1440	9.405	9.417	9.428	9.439	9.451	9.462	9.474	9.485	9.497	9.508	9.519	1440
1450	9.519	9.531	9.542	9.554	9.565	9.577	9.588	9.599	9.611	9.622	9.634	1450
1460	9.634	9.645	9.657	9.668	9.680	9.691	9.703	9.714	9.726	9.737	9.748	1460
1470	9.748	9.760	9.771	9.783	9.794	9.806	9.817	9.829	9.840	9.852	9.863	1470
1480	9.863	9.875	9.886	9.898	9.909	9.921	9.933	9.944	9.956	9.967	9.979	1480
1490	9.979	9.990	10.002	10.013	10.025	10.036	10.048	10.059	10.071	10.082	10.094	1490
1500	10.094	10.106	10.117	10.129	10.140	10.152	10.163	10.175	10.187	10.198	10.210	1500
1510	10.210	10.221	10.233	10.244	10.256	10.268	10.279	10.291	10.302	10.314	10.325	1510
1520	10.325	10.337	10.349	10.360	10.372	10.383	10.395	10.407	10.418	10.430	10.441	1520
1530	10.441	10.453	10.465	10.476	10.488	10.500	10.511	10.523	10.534	10.546	10.558	1530
1540	10.558	10.569	10.581	10.593	10.604	10.616	10.627	10.639	10.651	10.662	10.674	1540
1550	10.674	10.686	10.697	10.709	10.721	10.732	10.744	10.756	10.767	10.779	10.790	1550
DEG C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DEG C**

Table 11 (continued) — Temperature-EMF for type B thermocouples

Temperatures in degrees Celsius (IPTS-68)   Reference junctions at 0°C

THERMOELECTRIC VOLTAGE IN MILLIVOLTS

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
1560	10.790	10.802	10.814	10.825	10.837	10.849	10.860	10.872	10.884	10.895	10.907	1560
1570	10.907	10.919	10.930	10.942	10.954	10.965	10.977	10.989	11.000	11.012	11.024	1570
1580	11.024	11.035	11.047	11.059	11.070	11.082	11.094	11.105	11.117	11.129	11.141	1580
1590	11.141	11.152	11.164	11.176	11.187	11.199	11.211	11.222	11.234	11.246	11.257	1590
1600	11.257	11.269	11.281	11.292	11.304	11.316	11.328	11.339	11.351	11.363	11.374	1600
1610	11.374	11.386	11.398	11.409	11.421	11.433	11.444	11.456	11.468	11.480	11.491	1610
1620	11.491	11.503	11.515	11.526	11.538	11.550	11.561	11.573	11.585	11.597	11.608	1620
1630	11.608	11.620	11.632	11.643	11.655	11.667	11.678	11.690	11.702	11.714	11.725	1630
1640	11.725	11.737	11.749	11.760	11.772	11.784	11.795	11.807	11.819	11.830	11.842	1640
1650	11.842	11.854	11.866	11.877	11.889	11.901	11.912	11.924	11.936	11.947	11.959	1650
1660	11.959	11.971	11.983	11.994	12.006	12.018	12.029	12.041	12.053	12.064	12.076	1660
1670	12.076	12.088	12.099	12.111	12.123	12.134	12.146	12.158	12.170	12.181	12.193	1670
1680	12.193	12.205	12.216	12.228	12.240	12.251	12.263	12.275	12.286	12.298	12.310	1680
1690	12.310	12.321	12.333	12.345	12.356	12.368	12.380	12.391	12.403	12.415	12.426	1690
1700	12.426	12.438	12.450	12.461	12.473	12.485	12.496	12.508	12.520	12.531	12.543	1700
1710	12.543	12.555	12.566	12.578	12.590	12.601	12.613	12.624	12.636	12.648	12.659	1710
1720	12.659	12.671	12.683	12.694	12.706	12.718	12.729	12.741	12.752	12.764	12.776	1720
1730	12.776	12.787	12.799	12.811	12.822	12.834	12.845	12.857	12.869	12.880	12.892	1730
1740	12.892	12.903	12.915	12.927	12.938	12.950	12.961	12.973	12.985	12.996	13.008	1740
1750	13.008	13.019	13.031	13.043	13.054	13.066	13.077	13.089	13.100	13.112	13.124	1750
1760	13.124	13.135	13.147	13.158	13.170	13.181	13.193	13.204	13.216	13.228	13.239	1760
1770	13.239	13.251	13.262	13.274	13.285	13.297	13.308	13.320	13.331	13.343	13.354	1170
1780	13.354	13.366	13.378	13.389	13.401	13.412	13.424	13.435	13.447	13.458	13.470	1780
1790	13.470	13.481	13.493	13.504	13.516	13.527	13.539	13.550	13.562	13.573	13.585	1790
1800	13.585	13.596	13.607	13.619	13.630	13.642	13.653	13.665	13.676	13.688	13.699	1800
1810	13.699	13.711	13.722	13.733	13.745	13.756	13.768	13.779	13.791	13.802	13.814	1810
1820	13.814											1820
DEG C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DEG C**

Table 12 — Temperature-EMF for type E thermocouples

Temperatures in degrees Celsius (IPTS-68) **Reference junctions at 0°C**

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
					THERMOELECTRIC VOLTAGE IN MILLIVOLTS							
–270	–9.835											–270
–260	–9.797	–9.802	–9.808	–9.813	–9.817	–9.821	–9.825	–9.828	–9.831	–9.833	–9.835	–260
–250	–9.719	–9.728	–9.737	–9.746	–9.754	–9.762	–9.770	–9.777	–9.784	–9.791	–9.797	–250
–240	–9.604	–9.617	–9.630	–9.642	–9.654	–9.666	–9.677	–9.688	–9.699	–9.709	–9.719	–240
–230	–9.455	–9.472	–9.488	–9.503	–9.519	–9.534	–9.549	–9.563	–9.577	–9.591	–9.604	–230
–220	–9.274	–9.293	–9.313	–9.332	–9.350	–9.368	–9.386	–9.404	–9.421	–9.438	–9.455	–220
–210	–9.063	–9.085	–9.107	–9.129	–9.151	–9.172	–9.193	–9.214	–9.234	–9.254	–9.274	–210
–200	–8.824	–8.850	–8.874	–8.899	–8.923	–8.947	–8.971	–8.994	–9.017	–9.040	–9.063	–200
–190	–8.561	–8.588	–8.615	–8.642	–8.669	–8.696	–8.722	–8.748	–8.774	–8.799	–8.824	–190
–180	–8.273	–8.303	–8.333	–8.362	–8.391	–8.420	–8.449	–8.477	–8.505	–8.533	–8.561	–180
–170	–7.963	–7.995	–8.027	–8.058	–8.090	–8.121	–8.152	–8.183	–8.213	–8.243	–8.273	–170
–160	–7.631	–7.665	–7.699	–7.733	–7.767	–7.800	–7.833	–7.866	–7.898	–7.931	–7.963	–160
–150	–7.279	–7.315	–7.351	–7.387	–7.422	–7.458	–7.493	–7.528	–7.562	–7.597	–7.631	–150
–140	–6.907	–6.945	–6.983	–7.020	–7.058	–7.095	–7.132	–7.169	–7.206	–7.243	–7.279	–140
–130	–6.516	–6.556	–6.596	–6.635	–6.675	–6.714	–6.753	–6.792	–6.830	–6.869	–6.907	–130
–120	–6.107	–6.149	–6.190	–6.231	–6.273	–6.314	–6.354	–6.395	–6.436	–6.476	–6.516	–120
–110	–5.680	–5.724	–5.767	–5.810	–5.853	–5.896	–5.938	–5.981	–6.023	–6.065	–6.107	–110
–100	–5.237	–5.282	–5.327	–5.371	–5.416	–5.460	–5.505	–5.549	–5.593	–5.637	–5.680	–100
–90	–4.777	–4.824	–4.870	–4.916	–4.963	–5.009	–5.055	–5.100	–5.146	–5.191	–5.237	–90
–80	–4.301	–4.350	–4.398	–4.446	–4.493	–4.541	–4.588	–4.636	–4.683	–4.730	–4.777	–80
–70	–3.811	–3.860	–3.910	–3.959	–4.009	–4.058	–4.107	–4.156	–4.204	–4.253	–4.301	–70
–60	–3.306	–3.357	–3.408	–3.459	–3.509	–3.560	–3.610	–3.661	–3.711	–3.761	–3.811	–60
–50	–2.787	–2.839	–2.892	–2.944	–2.996	–3.048	–3.100	–3.152	–3.203	–3.254	–3.306	–50
–40	–2.254	–2.308	–2.362	–2.416	–2.469	–2.522	–2.575	–2.628	–2.681	–2.734	–2.787	–40
–30	–1.709	–1.764	–1.819	–1.874	–1.929	–1.983	–2.038	–2.092	–2.146	–2.200	–2.254	–30
–20	–1.151	–1.208	–1.264	–1.320	–1.376	–1.432	–1.487	–1.543	–1.599	–1.654	–1.709	–20
–10	–0.581	–0.639	–0.696	–0.754	–0.811	–0.868	–0.925	–0.982	–1.038	–1.095	–1.151	–10
–0	0.000	–0.059	–0.117	–0.176	–0.234	–0.292	–0.350	–0.408	–0.466	–0.524	–0.581	–0
0	0.000	0.059	0.118	0.176	0.235	0.295	0.354	0.413	0.472	0.532	0.591	0
10	0.591	0.651	0.711	0.770	0.830	0.890	0.950	1.011	1.071	1.131	1.192	10
20	1.192	1.252	1.313	1.373	1.434	1.495	1.556	1.617	1.678	1.739	1.801	20
30	1.801	1.862	1.924	1.985	2.047	2.109	2.171	2.233	2.295	2.357	2.419	30
40	2.419	2.482	2.544	2.607	2.669	2.732	2.795	2.858	2.921	2.984	3.047	40
50	3.047	3.110	3.173	3.237	3.300	3.364	3.428	3.491	3.555	3.619	3.683	50
60	3.683	3.748	3.812	3.876	3.941	4.005	4.070	4.134	4.199	4.264	4.329	60
70	4.329	4.394	4.459	4.524	4.590	4.655	4.720	4.786	4.852	4.917	4.983	70
80	4.983	5.049	5.115	5.181	5.247	5.314	5.380	5.446	5.513	5.579	5.646	80
90	5.646	5.713	5.780	5.846	5.913	5.981	6.048	6.115	6.182	6.250	6.317	90
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 12 (continued) — Temperature-EMF for type E thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

THERMOELECTRIC VOLTAGE IN MILLIVOLTS

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
100	6.317	6.385	6.452	6.520	6.588	6.656	6.724	6.792	6.860	6.928	6.996	100
110	6.996	7.064	7.133	7.201	7.270	7.339	7.407	7.476	7.545	7.614	7.683	110
120	7.683	7.752	7.821	7.890	7.960	8.029	8.099	8.168	8.238	8.307	8.377	120
130	8.377	8.447	8.517	8.587	8.657	8.727	8.797	8.867	8.938	9.008	9.078	130
140	9.078	9.149	9.220	9.290	9.361	9.432	9.503	9.573	9.644	9.715	9.787	140
150	9.787	9.858	9.929	10.000	10.072	10.143	10.215	10.286	10.358	10.429	10.501	150
160	10.501	10.573	10.645	10.717	10.789	10.861	10.933	11.005	11.077	11.150	11.222	160
170	11.222	11.294	11.367	11.439	11.512	11.585	11.657	11.730	11.803	11.876	11.949	170
180	11.949	12.022	12.095	12.168	12.241	12.314	12.387	12.461	12.534	12.608	12.681	180
190	12.681	12.755	12.828	12.902	12.975	13.049	13.123	13.197	13.271	13.345	13.419	190
200	13.419	13.493	13.567	13.641	13.715	13.789	13.864	13.938	14.012	14.087	14.161	200
210	14.161	14.236	14.310	14.385	14.460	14.534	14.609	14.684	14.759	14.834	14.909	210
220	14.909	14.984	15.059	15.134	15.209	15.284	15.359	15.435	15.510	15.585	15.661	220
230	15.661	15.736	15.812	15.887	15.963	16.038	16.114	16.190	16.266	16.341	16.417	230
240	16.417	16.493	16.569	16.645	16.721	16.797	16.873	16.949	17.025	17.101	17.178	240
250	17.178	17.254	17.330	17.406	17.483	17.559	17.636	17.712	17.789	17.865	17.942	250
260	17.942	18.018	18.095	18.172	18.248	18.325	18.402	18.479	18.556	18.633	18.710	260
270	18.710	18.787	18.864	18.941	19.018	19.095	19.172	19.249	19.326	19.404	19.481	270
280	19.481	19.558	19.636	19.713	19.790	19.868	19.945	20.023	20.100	20.178	20.256	280
290	20.256	20.333	20.411	20.488	20.566	20.644	20.722	20.800	20.877	20.955	21.033	290
300	21.033	21.111	21.189	21.267	21.345	21.423	21.501	21.579	21.657	21.735	21.814	300
310	21.814	21.892	21.970	22.048	22.127	22.205	22.283	22.362	22.440	22.518	22.597	310
320	22.597	22.675	22.754	22.832	22.911	22.989	23.068	23.147	23.225	23.304	23.383	320
330	23.383	23.461	23.540	23.619	23.698	23.777	23.855	23.934	24.013	24.092	24.171	330
340	24.171	24.250	24.329	24.408	24.487	24.566	24.645	24.724	24.803	24.882	24.961	340
350	24.961	25.041	25.120	25.199	25.278	25.357	25.437	25.516	25.595	25.675	25.754	350
360	25.754	25.833	25.913	25.992	26.072	26.151	26.230	26.310	26.389	26.469	26.549	360
370	26.549	26.628	26.708	26.787	26.867	26.947	27.026	27.106	27.186	27.265	27.345	370
380	27.345	27.425	27.504	27.584	27.664	27.744	27.824	27.903	27.983	28.063	28.143	380
390	28.143	28.223	28.303	28.383	28.463	28.543	28.623	28.703	28.783	28.863	28.943	390
400	28.943	29.023	29.103	29.183	29.263	29.343	29.423	29.503	29.584	29.664	29.744	400
410	29.744	29.824	29.904	29.984	30.065	30.145	30.225	30.305	30.386	30.466	30.546	410
420	30.546	30.627	30.707	30.787	30.868	30.948	31.028	31.109	31.189	31.270	31.350	420
430	31.350	31.430	31.511	31.591	31.672	31.752	31.833	31.913	31.994	32.074	32.155	430
440	32.155	32.235	32.316	32.396	32.477	32.557	32.638	32.719	32.799	32.880	32.960	440
450	32.960	33.041	33.122	33.202	33.283	33.364	33.444	33.525	33.605	33.686	33.767	450
460	33.767	33.848	33.928	34.009	34.090	34.170	34.251	34.332	34.413	34.493	34.574	460
470	34.574	34.655	34.736	34.816	34.897	34.978	35.059	35.140	35.220	35.301	35.382	470
480	35.382	35.463	35.544	35.624	35.705	35.786	35.867	35.948	36.029	36.109	36.190	480
DEG C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DEG C**

Table 12 (continued) — Temperature-EMF for type E thermocouples
Temperatures in degrees Celsius (IPTS-68)   Reference junctions at 0°C

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
						THERMOELECTRIC VOLTAGE IN MILLIVOLTS						
490	36.190	36.271	36.352	36.433	36.514	36.595	36.675	36.756	36.837	36.918	36.999	490
500	36.999	37.080	37.161	37.242	37.323	37.403	37.484	37.565	37.646	37.727	37.808	500
510	37.808	37.889	37.970	38.051	38.132	38.213	38.293	38.374	38.455	38.536	38.617	510
520	38.617	38.698	38.779	38.860	38.941	39.022	39.103	39.184	39.264	39.345	39.426	520
530	39.426	39.507	39.588	39.669	39.750	39.831	39.912	39.993	40.074	40.155	40.236	530
540	40.236	40.316	40.397	40.478	40.559	40.640	40.721	40.802	40.883	40.964	41.045	540
550	41.045	41.125	41.206	41.287	41.368	41.449	41.530	41.611	41.692	41.773	41.853	550
560	41.853	41.934	42.015	42.096	42.177	42.258	42.339	42.419	42.500	42.581	42.662	560
570	42.662	42.743	42.824	42.904	42.985	43.066	43.147	43.228	43.308	43.389	43.470	570
580	43.470	43.551	43.632	43.712	43.793	43.874	43.955	44.035	44.116	44.197	44.278	580
590	44.278	44.358	44.439	44.520	44.601	44.681	44.762	44.843	44.923	45.004	45.085	590
600	45.085	45.165	45.246	45.327	45.407	45.488	45.569	45.649	45.730	45.811	45.891	600
610	45.891	45.972	46.052	46.133	46.213	46.294	46.375	46.455	46.536	46.616	46.697	610
620	46.697	46.777	46.858	46.938	47.019	47.099	47.180	47.260	47.341	47.421	47.502	620
630	47.502	47.582	47.663	47.743	47.824	47.904	47.984	48.065	48.145	48.226	48.306	630
640	48.306	48.386	48.467	48.547	48.627	48.708	48.788	48.868	48.949	49.029	49.109	640
650	49.109	49.189	49.270	49.350	49.430	49.510	49.591	49.671	49.751	49.831	49.911	650
660	49.911	49.992	50.072	50.152	50.232	50.312	50.392	50.472	50.553	50.633	50.713	660
670	50.713	50.793	50.873	50.953	51.033	51.113	51.193	51.273	51.353	51.433	51.513	670
680	51.513	51.593	51.673	51.753	51.833	51.913	51.993	52.073	52.152	52.232	52.312	680
690	52.312	52.392	52.472	52.552	52.632	52.711	52.791	52.871	52.951	53.031	53.110	690
700	53.110	53.190	53.270	53.350	53.429	53.509	53.589	53.668	53.748	53.828	53.907	700
710	53.907	53.987	54.066	54.146	54.226	54.305	54.385	54.464	54.544	54.623	54.703	710
720	54.703	54.782	54.862	54.941	55.021	55.100	55.180	55.259	55.339	55.418	55.498	720
730	55.498	55.577	55.656	55.736	55.815	55.894	55.974	56.053	56.132	56.212	56.291	730
740	56.291	56.370	56.449	56.529	56.608	56.687	56.766	56.845	56.924	57.004	57.083	740
750	57.083	57.162	57.241	57.320	57.399	57.478	57.557	57.636	57.715	57.794	57.873	750
760	57.873	57.952	58.031	58.110	58.189	58.268	58.347	58.426	58.505	58.584	58.663	760
770	58.663	58.742	58.820	58.899	58.978	59.057	59.136	59.214	59.293	59.372	59.451	770
780	59.451	59.529	59.608	59.687	59.765	59.844	59.923	60.001	60.080	60.159	60.237	780
790	60.237	60.316	60.394	60.473	60.551	60.630	60.708	60.787	60.865	60.944	61.022	790
800	61.022	61.101	61.179	61.258	61.336	61.414	61.493	61.571	61.649	61.728	61.806	800
810	61.806	61.884	61.962	62.041	62.119	62.197	62.275	62.353	62.432	62.510	62.588	810
820	62.588	62.666	62.744	62.822	62.900	92.978	63.056	63.134	63.212	63.290	63.368	820
830	63.368	63.446	63.524	63.602	63.680	63.758	63.836	63.914	63.992	64.069	64.147	830
840	64.147	64.225	64.303	64.380	64.458	64.536	64.614	64.691	64.769	64.847	64.924	840
850	64.924	65.002	65.080	65.157	65.235	65.312	65.390	65.467	65.545	65.622	65.700	850
860	65.700	65.777	65.855	65.932	66.009	66.087	66.164	66.241	66.319	66.396	66.473	860
870	66.473	66.551	66.628	66.705	66.782	66.859	66.937	67.014	67.091	67.168	67.245	870
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 12 (continued) — Temperature–EMF for type E thermocouples

Temperatures in degrees Celsius (IPTS–68) Reference junctions at 0°C

THERMOELECTRIC VOLTAGE IN MILLIVOLTS

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
880	67.245	67.322	67.399	67.476	67.553	67.630	67.707	67.784	67.861	67.938	68.015	880
890	68.015	68.092	68.169	68.246	68.323	68.399	68.476	68.553	68.630	68.706	68.783	890
900	68.783	68.860	68.936	69.013	69.090	69.166	69.243	69.320	69.396	69.473	69.549	900
910	69.549	69.626	69.702	69.779	69.855	69.931	70.008	70.084	70.161	70.237	70.313	910
920	70.313	70.390	70.466	70.542	70.618	70.694	70.771	70.847	70.923	70.999	71.075	920
930	71.075	71.151	71.227	71.303	71.380	71.456	71.532	71.608	71.683	71.759	71.835	930
940	71.835	71.911	71.987	72.063	72.139	72.215	72.290	72.366	72.442	72.518	72.593	940
950	72.593	72.669	72.745	72.820	72.896	72.972	73.047	73.123	73.199	73.274	73.350	950
960	73.350	73.425	73.501	73.576	73.652	73.727	73.802	73.878	73.953	74.029	74.104	960
970	74.104	74.179	74.255	74.330	74.405	74.480	74.556	74.631	74.706	74.781	74.857	970
980	74.857	74.932	75.007	75.082	75.157	75.232	75.307	75.382	75.458	75.533	75.608	980
990	75.608	75.683	75.758	75.833	75.908	75.983	76.058	76.133	76.208	76.283	76.358	990
1000	76.358											1000
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 13 — Temperature for type J thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

THERMOELECTRIC VOLTAGE IN MILLIVOLTS

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
–210	–8.096											–210
–200	–7.890	–7.912	–7.934	–7.955	–7.976	–7.996	–8.017	–8.037	–8.057	–8.076	–8.096	–200
–190	–7.659	–7.683	–7.707	–7.731	–7.755	–7.778	–7.801	–7.824	–7.846	–7.868	–7.890	–190
–180	–7.402	–7.429	–7.455	–7.482	–7.508	–7.533	–7.559	–7.584	–7.609	–7.634	–7.659	–180
–170	–7.122	–7.151	–7.180	–7.209	–7.237	–7.265	–7.293	–7.321	–7.348	–7.375	–7.402	–170
–160	–6.821	–6.852	–6.883	–6.914	–6.944	–6.974	–7.004	–7.034	–7.064	–7.093	–7.122	–160
–150	–6.499	–6.532	–6.565	–6.598	–6.630	–6.663	–6.695	–6.727	–6.758	–6.790	–6.821	–150
–140	–6.159	–6.194	–6.228	–6.263	–6.297	–6.331	–6.365	–6.399	–6.433	–6.466	–6.499	–140
–130	–5.801	–5.837	–5.874	–5.910	–5.946	–5.982	–6.018	–6.053	–6.089	–6.124	–6.159	–130
–120	–5.426	–5.464	–5.502	–5.540	–5.578	–5.615	–5.653	–5.690	–5.727	–5.764	–5.801	–120
–110	–5.036	–5.076	–5.115	–5.155	–5.194	–5.233	–5.272	–5.311	–5.349	–5.388	–5.426	–110
–100	–4.632	–4.673	–4.714	–4.755	–4.795	–4.836	–4.876	–4.916	–4.956	–4.996	–5.036	–100
–90	–4.215	–4.257	–4.299	–4.341	–4.383	–4.425	–4.467	–4.508	–4.550	–4.591	–4.632	–90
–80	–3.785	–3.829	–3.872	–3.915	–3.958	–4.001	–4.044	–4.087	–4.130	–4.172	–4.215	–80
–70	–3.344	–3.389	–3.433	–3.478	–3.522	–3.566	–3.610	–3.654	–3.698	–3.742	–3.785	–70
–60	–2.892	–2.938	–2.984	–3.029	–3.074	–3.120	–3.165	–3.210	–3.255	–3.299	–3.344	–60
–50	–2.431	–2.478	–2.524	–2.570	–2.617	–2.663	–2.709	–2.755	–2.801	–2.847	–2.892	–50
–40	–1.960	–2.008	–2.055	–2.102	–2.150	–2.197	–2.244	–2.291	–2.338	–2.384	–2.431	–40
–30	–1.481	–1.530	–1.578	–1.626	–1.674	–1.722	–1.770	–1.818	–1.865	–1.913	–1.960	–30
–20	–0.995	–1.044	–1.093	–1.141	–1.190	–1.239	–1.288	–1.336	–1.385	–1.433	–1.481	–20
–10	–0.501	–0.550	–0.600	–0.650	–0.699	–0.748	–0.798	–0.847	–0.896	–0.945	–0.995	–10
–0	0.000	–0.050	–0.101	–0.151	–0.201	–0.251	–0.301	–0.351	–0.401	–0.451	–0.501	–0
0	0.000	0.050	0.101	0.151	0.202	0.253	0.303	0.354	0.405	0.456	0.507	0
10	0.507	0.558	0.609	0.660	0.711	0.762	0.813	0.865	0.916	0.967	1.019	10
20	1.019	1.070	1.122	1.174	1.225	1.277	1.329	1.381	1.432	1.484	1.536	20
30	1.536	1.588	1.640	1.693	1.745	1.797	1.849	1.901	1.954	2.006	2.058	30
40	2.058	2.111	2.163	2.216	2.268	2.321	2.374	2.426	2.479	2.532	2.585	40
50	2.585	2.638	2.691	2.743	2.796	2.849	2.902	2.956	3.009	3.062	3.115	50
60	3.115	3.168	3.221	3.275	3.328	3.381	3.435	3.488	3.542	3.595	3.649	60
70	3.649	3.702	3.756	3.809	3.863	3.917	3.971	4.024	4.078	4.132	4.186	70
80	4.186	4.239	4.293	4.347	4.401	4.455	4.509	4.563	4.617	4.671	4.725	80
90	4.725	4.780	4.834	4.888	4.942	4.996	5.050	5.105	5.159	5.213	5.268	90
100	5.268	5.322	5.376	5.431	5.485	5.540	5.594	5.649	5.703	5.758	5.812	100
110	5.812	5.867	5.921	5.976	6.031	6.085	6.140	6.195	6.249	6.304	6.359	110
120	6.359	6.414	6.468	6.523	6.578	6.633	6.688	6.742	6.797	6.852	6.907	120
130	6.907	6.962	7.017	7.072	7.127	7.182	7.237	7.292	7.347	7.402	7.457	130
140	7.457	7.512	7.567	7.622	7.677	7.732	7.787	7.843	7.898	7.953	8.008	140
150	8.008	8.063	8.118	8.174	8.229	8.284	8.339	8.394	8.450	8.505	8.560	150
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 13 (continued) — Temperature for type J thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

THERMOELECTRIC VOLTAGE IN MILLIVOLTS

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
160	8.560	8.616	8.671	8.726	8.781	8.837	8.892	8.947	9.003	9.058	9.113	160
170	9.113	9.169	9.224	9.279	9.335	9.390	9.446	9.501	9.556	9.612	9.667	170
180	9.667	9.723	9.778	9.834	9.889	9.944	10.000	10.055	10.111	10.166	10.222	180
190	10.222	10.277	10.333	10.388	10.444	10.499	10.555	10.610	10.666	10.721	10.777	190
200	10.777	10.832	10.888	10.943	10.999	11.054	11.110	11.165	11.221	11.276	11.332	200
210	11.332	11.387	11.443	11.498	11.554	11.609	11.665	11.720	11.776	11.831	11.887	210
220	11.887	11.943	11.998	12.054	12.109	12.165	12.220	12.276	12.331	12.387	12.442	220
230	12.442	12.498	12.553	12.609	12.664	12.720	12.776	12.831	12.887	12.942	12.998	230
240	12.998	13.053	13.109	13.164	13.220	13.275	13.331	13.386	13.442	13.497	13.553	240
250	13.553	13.608	13.664	13.719	13.775	13.830	13.886	13.941	13.997	14.052	14.108	250
260	14.108	14.163	14.219	14.274	14.330	14.385	14.441	14.496	14.552	14.607	14.663	260
270	14.663	14.718	14.774	14.829	14.885	14.940	14.995	15.051	15.106	15.162	15.217	270
280	15.217	15.273	15.328	15.383	15.439	15.494	15.550	15.605	15.661	15.716	15.771	280
290	15.771	15.827	15.882	15.938	15.993	16.048	16.104	16.159	16.214	16.270	16.325	290
300	16.325	16.380	16.436	16.491	16.547	16.602	16.657	16.713	16.768	16.823	16.879	300
310	16.879	16.934	16.989	17.044	17.100	17.155	17.210	17.266	17.321	17.376	17.432	310
320	17.432	17.487	17.542	17.597	17.653	17.708	17.763	17.818	17.874	17.929	17.984	320
330	17.984	18.039	18.095	18.150	18.205	18.260	18.316	18.371	18.426	18.481	18.537	330
340	18.537	18.592	18.647	18.702	18.757	18.813	18.868	18.923	18.978	19.033	19.089	340
350	19.089	19.144	19.199	19.254	19.309	19.364	19.420	19.475	19.530	19.585	19.640	350
360	19.640	19.695	19.751	19.806	19.861	19.916	19.971	20.026	20.081	20.137	20.192	360
370	20.192	20.247	20.302	20.357	20.412	20.467	20.523	20.578	20.633	20.688	20.743	370
380	20.743	20.798	20.853	20.909	20.964	21.019	21.074	21.129	21.184	21.239	21.295	380
390	21.295	21.350	21.405	21.460	21.515	21.570	21.625	21.680	21.736	21.791	21.846	390
400	21.846	21.901	21.956	22.011	22.066	22.122	22.177	22.232	22.287	22.342	22.397	400
410	22.397	22.453	22.508	22.563	22.618	22.673	22.728	22.784	22.839	22.894	22.949	410
420	22.949	23.004	23.060	23.115	23.170	23.225	23.280	23.336	23.391	23.446	23.501	420
430	23.501	23.556	23.612	23.667	23.722	23.777	23.833	23.888	23.943	23.999	24.054	430
440	24.054	24.109	24.164	24.220	24.275	24.330	24.386	24.441	24.496	24.552	24.607	440
450	24.607	24.662	24.718	24.773	24.829	24.884	24.939	24.995	25.050	25.106	25.161	450
460	25.161	25.217	25.272	25.327	25.383	25.438	25.494	25.549	25.605	25.661	25.716	460
470	25.716	25.772	25.827	25.883	25.938	25.994	26.050	26.105	26.161	26.216	26.272	470
480	26.272	26.328	26.383	26.439	26.495	26.551	26.606	26.662	26.718	26.774	26.829	480
490	26.829	26.885	26.941	26.997	27.053	27.109	27.165	27.220	27.276	27.332	27.388	490
500	27.388	27.444	27.500	27.556	27.612	27.668	27.724	27.780	27.836	27.893	27.949	500
510	27.949	28.005	28.061	28.117	28.173	28.230	28.286	28.342	28.398	28.455	28.511	510
520	28.511	28.567	28.624	28.680	28.736	28.793	28.849	28.906	28.962	29.019	29.075	520
530	29.075	29.132	29.188	29.245	29.301	29.358	29.415	29.471	29.528	29.585	29.642	530
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 13 (continued) — Temperature for type J thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
						THERMOELECTRIC VOLTAGE IN MILLIVOLTS						
540	29.642	29.698	29.755	29.812	29.869	29.926	29.983	30.039	30.096	30.153	30.210	540
550	30.210	30.267	30.324	30.381	30.439	30.496	30.553	30.610	30.667	30.724	30.782	550
560	30.782	30.839	30.896	30.954	31.011	31.068	31.126	31.183	31.241	31.298	31.356	560
570	31.356	31.413	31.471	31.528	31.586	31.644	31.702	31.759	31.817	31.875	31.933	570
580	31.933	31.991	32.048	32.106	32.164	32.222	32.280	32.338	32.396	32.455	32.513	580
590	32.513	32.571	32.629	32.687	32.746	32.804	32.862	32.921	32.979	33.038	33.096	590
600	33.096	33.155	33.213	33.272	33.330	33.389	33.448	33.506	33.565	33.624	33.683	600
610	33.683	33.742	33.800	33.859	33.918	33.977	34.036	34.095	34.155	34.214	34.273	610
620	34.273	34.332	34.391	34.451	34.510	34.569	34.629	34.688	34.748	34.807	34.867	620
630	34.867	34.926	34.986	35.046	35.105	35.165	35.225	35.285	35.344	35.404	35.464	630
640	35.464	35.524	35.584	35.644	35.704	35.764	35.825	35.885	35.945	36.005	36.066	640
650	36.066	36.126	36.186	36.247	36.307	36.368	36.428	36.489	36.549	36.610	36.671	650
660	36.671	36.732	36.792	36.853	36.914	36.975	37.036	37.097	37.158	37.219	37.280	660
670	37.280	37.341	37.402	37.463	37.525	37.586	37.647	37.709	37.770	37.831	37.893	670
680	37.893	37.954	38.016	38.078	38.139	38.201	38.262	38.324	38.386	38.448	38.510	680
690	38.510	38.572	38.633	38.695	38.757	38.819	38.882	38.944	39.006	39.068	39.130	690
700	39.130	39.192	39.255	39.317	39.379	39.442	39.504	39.567	39.629	39.692	39.754	700
710	39.754	39.817	39.880	39.942	40.005	40.068	40.131	40.193	40.256	40.319	40.382	710
720	40.382	40.445	40.508	40.571	40.634	40.697	40.760	40.823	40.886	40.950	41.013	720
730	41.013	41.076	41.139	41.203	41.266	41.329	41.393	41.456	41.520	41.583	41.647	730
740	41.647	41.710	41.774	41.837	41.901	41.965	42.028	42.092	42.156	42.219	42.283	740
750	42.283	42.347	42.411	42.475	42.538	42.602	42.666	42.730	42.794	42.858	42.922	750
760	42.922											760
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 14 — Temperature-EMF for Type K thermocouples

Temperatures in degrees Celsius (IPTS-68)　　Reference junctions at 0°C

THERMOELECTRIC VOLTAGE IN MILLIVOLTS

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
–270	–6.458											–270
–260	–6.441	–6.444	–6.446	–6.448	–6.450	–6.452	–6.453	–6.455	–6.456	–6.457	–6.458	–260
–250	–6.404	–6.408	–6.413	–6.417	–6.421	–6.425	–6.429	–6.432	–6.435	–6.438	–6.441	–250
–240	–6.344	–6.351	–6.358	–6.364	–6.371	–6.377	–6.382	–6.388	–6.394	–6.399	–6.404	–240
–230	–6.262	–6.271	–6.280	–6.289	–6.297	–6.306	–6.314	–6.322	–6.329	–6.337	–6.344	–230
–220	–6.158	–6.170	–6.181	–6.192	–6.202	–6.213	–6.223	–6.233	–6.243	–6.253	–6.262	–220
–210	–6.035	–6.048	–6.061	–6.074	–6.087	–6.099	–6.111	–6.123	–6.135	–6.147	–6.158	–210
–200	–5.891	–5.907	–5.922	–5.936	–5.951	–5.965	–5.980	–5.994	–6.007	–6.021	–6.035	–200
–190	–5.730	–5.747	–5.763	–5.780	–5.796	–5.813	–5.829	–5.845	–5.860	–5.876	–5.891	–190
–180	–5.550	–5.569	–5.587	–5.606	–5.624	–5.642	–5.660	–5.678	–5.695	–5.712	–5.730	–180
–170	–5.354	–5.374	–5.394	–5.414	–5.434	–5.454	–5.474	–5.493	–5.512	–5.531	–5.550	–170
–160	–5.141	–5.163	–5.185	–5.207	–5.228	–5.249	–5.271	–5.292	–5.313	–5.333	–5.354	–160
–150	–4.912	–4.936	–4.959	–4.983	–5.006	–5.029	–5.051	–5.074	–5.097	–5.119	–5.141	–150
–140	–4.669	–4.694	–4.719	–4.743	–4.768	–4.792	–4.817	–4.841	–4.865	–4.889	–4.912	–140
–130	–4.410	–4.437	–4.463	–4.489	–4.515	–4.541	–4.567	–4.593	–4.618	–4.644	–4.669	–130
–120	–4.138	–4.166	–4.193	–4.221	–4.248	–4.276	–4.303	–4.330	–4.357	–4.384	–4.410	–120
–110	–3.852	–3.881	–3.910	–3.939	–3.968	–3.997	–4.025	–4.053	–4.082	–4.110	–4.138	–110
–100	–3.553	–3.584	–3.614	–3.644	–3.674	–3.704	–3.734	–3.764	–3.793	–3.823	–3.852	–100
–90	–3.242	–3.274	–3.305	–3.337	–3.368	–3.399	–3.430	–3.461	–3.492	–3.523	–3.553	–90
–80	–2.920	–2.953	–2.985	–3.018	–3.050	–3.082	–3.115	–3.147	–3.179	–3.211	–3.242	–80
–70	–2.586	–2.620	–2.654	–2.687	–2.721	–2.754	–2.788	–2.821	–2.854	–2.887	–2.920	–70
–60	–2.243	–2.277	–2.312	–2.347	–2.381	–2.416	–2.450	–2.484	–2.518	–2.552	–2.586	–60
–50	–1.889	–1.925	–1.961	–1.996	–2.032	–2.067	–2.102	–2.137	–2.173	–2.208	–2.243	–50
–40	–1.527	–1.563	–1.600	–1.636	–1.673	–1.709	–1.745	–1.781	–1.817	–1.853	–1.889	–40
–30	–1.156	–1.193	–1.231	–1.268	–1.305	–1.342	–1.379	–1.416	–1.453	–1.490	–1.527	–30
–20	–0.777	–0.816	–0.854	–0.892	–0.930	–0.968	–1.005	–1.043	–1.081	–1.118	–1.156	–20
–10	–0.392	–0.431	–0.469	–0.508	–0.547	–0.585	–0.624	–0.662	–0.701	–0.739	–0.777	–10
–0	0.000	–0.039	–0.079	–0.118	–0.157	–0.197	–0.236	–0.275	–0.314	–0.353	–0.392	–0
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397	0
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798	10
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.162	1.203	20
30	1.203	1.244	1.285	1.325	1.366	1.407	1.448	1.489	1.529	1.570	1.611	30
40	1.611	1.652	1.693	1.734	1.776	1.817	1.858	1.899	1.940	1.981	2.022	40
50	2.022	2.064	2.105	2.146	2.188	2.229	2.270	2.312	2.353	2.394	2.436	50
60	2.436	2.477	2.519	2.560	2.601	2.643	2.684	2.726	2.767	2.809	2.850	60
70	2.850	2.892	2.933	2.975	3.016	3.058	3.100	3.141	3.183	3.224	3.266	70
80	3.266	3.307	3.349	3.390	3.432	3.473	3.515	3.556	3.598	3.639	3.681	80
90	3.681	3.722	3.764	3.805	3.847	3.888	3.930	3.971	4.012	4.054	4.095	90
DEG C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DEG C**

Table 14 (continued) — Temperature-EMF for type K thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
						THERMOELECTRIC VOLTAGE IN MILLIVOLTS						
100	4.095	4.137	4.178	4.219	4.261	4.302	4.343	4.384	4.426	4.467	4.508	100
110	4.508	4.549	4.590	4.632	4.673	4.714	4.755	4.796	4.837	4.878	4.919	110
120	4.919	4.960	5.001	5.042	5.083	5.124	5.164	5.205	5.246	5.287	5.327	120
130	5.327	5.368	5.409	5.450	5.490	5.531	5.571	5.612	5.652	5.693	5.733	130
140	5.733	5.774	5.814	5.855	5.895	5.936	5.976	6.016	6.057	6.097	6.137	140
150	6.137	6.177	6.218	6.258	6.298	6.338	6.378	6.419	6.459	6.499	6.539	150
160	6.539	6.579	6.619	6.659	6.699	6.739	6.779	6.819	6.859	6.899	6.939	160
170	6.939	6.979	7.019	7.059	7.099	7.139	7.179	7.219	7.259	7.299	7.338	170
180	7.338	7.378	7.418	7.458	7.498	7.538	7.578	7.618	7.658	7.697	7.737	180
190	7.737	7.777	7.817	7.857	7.897	7.937	7.977	8.017	8.057	8.097	8.137	190
200	8.137	8.177	8.216	8.256	8.296	8.336	8.376	8.416	8.456	8.497	8.537	200
210	8.537	8.577	8.617	8.657	8.697	8.737	8.777	8.817	8.857	8.898	8.938	210
220	8.938	8.978	9.018	9.058	9.099	9.139	9.179	9.220	9.260	9.300	9.341	220
230	9.341	9.381	9.421	9.462	9.502	9.543	9.583	9.624	9.664	9.705	9.745	230
240	9.745	9.786	9.826	9.867	9.907	9.948	9.989	10.029	10.070	10.111	10.151	240
250	10.151	10.192	10.233	10.274	10.315	10.355	10.396	10.437	10.478	10.519	10.560	250
260	10.560	10.600	10.641	10.682	10.723	10.764	10.805	10.846	10.887	10.928	10.969	260
270	10.969	11.010	11.051	11.093	11.134	11.175	11.216	11.257	11.298	11.339	11.381	270
280	11.381	11.422	11.463	11.504	11.546	11.587	11.628	11.669	11.711	11.752	11.793	280
290	11.793	11.835	11.876	11.918	11.959	12.000	12.042	12.083	12.125	12.166	12.207	290
300	12.207	12.249	12.290	12.332	12.373	12.415	12.456	12.498	12.539	12.581	12.623	300
310	12.623	12.664	12.706	12.747	12.789	12.831	12.872	12.914	12.955	12.997	13.039	310
320	13.039	13.080	13.122	13.164	13.205	13.247	13.289	13.331	13.372	13.414	13.456	320
330	13.456	13.497	13.539	13.581	13.623	13.665	13.706	13.748	13.790	13.832	13.874	330
340	13.874	13.915	13.957	13.999	14.041	14.083	14.125	14.167	14.208	14.250	14.292	340
350	14.292	14.334	14.376	14.418	14.460	14.502	14.544	14.586	14.628	14.670	14.712	350
360	14.712	14.754	14.796	14.838	14.880	14.922	14.964	15.006	15.048	15.090	15.132	360
370	15.132	15.174	15.216	15.258	15.300	15.342	15.384	15.426	15.468	15.510	15.552	370
380	15.552	15.594	15.636	15.679	15.721	15.763	15.805	15.847	15.889	15.931	15.974	380
390	15.974	16.016	16.058	16.100	16.142	16.184	16.227	16.269	16.311	16.353	16.395	390
400	16.395	16.438	16.480	16.522	16.564	16.607	16.649	16.691	16.733	16.776	16.818	400
410	16.818	16.860	16.902	16.945	16.987	17.029	17.072	17.114	17.156	17.199	17.241	410
420	17.241	17.283	17.326	17.368	17.410	17.453	17.495	17.537	17.580	17.622	17.664	420
430	17.664	17.707	17.749	17.792	17.834	17.876	17.919	17.961	18.004	18.046	18.088	430
440	18.088	18.131	18.173	18.216	18.258	18.301	18.343	18.385	18.428	18.470	18.513	440
450	18.513	18.555	18.598	18.640	18.683	18.725	18.768	18.810	18.853	18.895	18.938	450
460	18.938	18.980	19.023	19.065	19.108	19.150	19.193	19.235	19.278	19.320	19.363	460
470	19.363	19.405	19.448	19.490	19.533	19.576	19.618	19.661	19.703	19.746	19.788	470
DEG C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DEG C**

Table 14 (continued) — Temperature-EMF for type K thermocouples
Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

THERMOELECTRIC VOLTAGE IN MILLIVOLTS

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
480	19.788	19.831	19.873	19.916	19.959	20.001	20.044	20.086	20.129	20.172	20.214	480
490	20.214	20.257	20.299	20.342	20.385	20.427	20.470	20.512	20.555	20.598	20.640	490
500	20.640	20.683	20.725	20.768	20.811	20.853	20.896	20.938	20.981	21.024	21.066	500
510	21.066	21.109	21.152	21.194	21.237	21.280	21.322	21.365	21.407	21.450	21.493	510
520	21.493	21.535	21.578	21.621	21.663	21.706	21.749	21.791	21.834	21.876	21.919	520
530	21.919	21.962	22.004	22.047	22.090	22.132	22.175	22.218	22.260	22.303	22.346	530
540	22.346	22.388	22.431	22.473	22.516	22.559	22.601	22.644	22.687	22.729	22.772	540
550	22.772	22.815	22.857	22.900	22.942	22.985	23.028	23.070	23.113	23.156	23.198	550
560	23.198	23.241	23.284	23.326	23.369	23.411	23.454	23.497	23.539	23.582	23.624	560
570	23.624	23.667	23.710	23.752	23.795	23.837	23.880	23.923	23.965	24.008	24.050	570
580	24.050	24.093	24.136	24.178	24.221	24.263	24.306	24.348	24.391	24.434	24.476	580
590	24.476	24.519	24.561	24.604	24.646	24.689	24.731	24.774	24.817	24.859	24.902	590
600	24.902	24.944	24.987	25.029	25.072	25.114	25.157	25.199	25.242	25.284	25.327	600
610	25.327	25.369	25.412	25.454	25.497	25.539	25.582	25.624	25.666	25.709	25.751	610
620	25.751	25.794	25.836	25.879	25.921	25.964	26.006	26.048	26.091	26.133	26.176	620
630	26.176	26.218	26.260	26.303	26.345	26.387	26.430	26.472	26.515	26.557	26.599	630
640	26.599	26.642	26.684	26.726	26.769	26.811	26.853	26.896	26.938	26.980	27.022	640
650	27.022	27.065	27.107	27.149	27.192	27.234	27.276	27.318	27.361	27.403	27.445	650
660	27.445	27.487	27.529	27.572	27.614	27.656	27.698	27.740	27.783	27.825	27.867	660
670	27.867	27.909	27.951	27.993	28.035	28.078	28.120	28.162	28.204	28.246	28.288	670
680	28.288	28.330	28.372	28.414	28.456	28.498	28.540	28.583	28.625	28.667	28.709	680
690	28.709	28.751	28.793	28.835	28.877	28.919	28.961	29.002	29.044	29.086	29.128	690
700	29.128	29.170	29.212	29.254	29.296	29.338	29.380	29.422	29.464	29.505	29.547	700
710	29.547	29.589	29.631	29.673	29.715	29.756	29.798	29.840	29.882	29.924	29.965	710
720	29.965	30.007	30.049	30.091	30.132	30.174	30.216	30.257	30.299	30.341	30.383	720
730	30.383	30.424	30.466	30.508	30.549	30.591	30.632	30.674	30.716	30.757	30.799	730
740	30.799	30.840	30.882	30.924	30.965	31.007	31.048	31.090	31.131	31.173	31.214	740
750	31.214	31.256	31.297	31.339	31.380	31.422	31.463	31.504	31.546	31.587	31.629	750
760	31.629	31.670	31.712	31.753	31.794	31.836	31.877	31.918	31.960	32.001	32.042	760
770	32.042	32.084	32.125	32.166	32.207	32.249	32.290	32.331	32.372	32.414	32.455	770
780	32.455	32.496	32.537	32.578	32.619	32.661	32.702	32.743	32.784	32.825	32.866	780
790	32.866	32.907	32.948	32.990	33.031	33.072	33.113	33.154	33.195	33.236	33.277	790
800	33.277	33.318	33.359	33.400	33.441	33.482	33.523	33.564	33.604	33.645	33.686	800
810	33.686	33.727	33.768	33.809	33.850	33.891	33.931	33.972	34.013	34.054	34.095	810
820	34.095	34.136	34.176	34.217	34.258	34.299	34.339	34.380	34.421	34.461	34.502	820
830	34.502	34.543	34.583	34.624	34.665	34.705	34.746	34.787	34.827	34.868	34.909	830
840	34.909	34.949	34.990	35.030	35.071	35.111	35.152	35.192	35.233	35.273	35.314	840
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 14 (continued) — Temperature-EMF for type K thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

THERMOELECTRIC VOLTAGE IN MILLIVOLTS

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
850	35.314	35.354	35.395	35.435	35.476	35.516	35.557	35.597	35.637	35.678	35.718	850
860	35.718	35.758	35.799	35.839	35.880	35.920	35.960	36.000	36.041	36.081	36.121	860
870	36.121	36.162	36.202	36.242	36.282	36.323	36.363	36.403	36.443	36.483	36.524	870
880	36.524	36.564	36.604	36.644	36.684	36.724	36.764	36.804	36.844	36.885	36.925	880
890	36.925	36.965	37.005	37.045	37.085	37.125	37.165	37.205	37.245	37.285	37.325	890
900	37.325	37.365	37.405	37.445	37.484	37.524	37.564	37.604	37.644	37.684	37.724	900
910	37.724	37.764	37.803	37.843	37.883	37.923	37.963	38.002	38.042	38.082	38.122	910
920	38.122	38.162	38.201	38.241	38.281	38.320	38.360	38.400	38.439	38.479	38.519	920
930	38.519	38.558	38.598	38.638	38.677	38.717	38.756	38.796	38.836	38.875	38.915	930
940	38.915	38.954	38.994	39.033	39.073	39.112	39.152	39.191	39.231	39.270	39.310	940
950	39.310	39.349	39.388	39.428	39.467	39.507	39.546	39.585	39.625	39.664	39.703	950
960	39.703	39.743	39.782	39.821	39.861	39.900	39.939	39.979	40.018	40.057	40.096	960
970	40.096	40.136	40.175	40.214	40.253	40.292	40.332	40.371	40.410	40.449	40.488	970
980	40.488	40.527	40.566	40.605	40.645	40.684	40.723	40.762	40.801	40.840	40.879	980
990	40.879	40.918	40.957	40.996	41.035	41.074	41.113	41.152	41.191	41.230	41.269	990
1000	41.269	41.308	41.347	41.385	41.424	41.463	41.502	41.541	41.580	41.619	41.657	1000
1010	41.657	41.696	41.735	41.774	41.813	41.851	41.890	41.929	41.968	42.006	42.045	1010
1020	42.045	42.084	42.123	42.161	42.200	42.239	42.277	42.316	42.355	42.393	42.432	1020
1030	42.432	42.470	42.509	42.548	42.586	42.625	42.663	42.702	42.740	42.779	42.817	1030
1040	42.817	42.856	42.894	42.933	42.971	43.010	43.048	43.087	43.125	43.164	43.202	1040
1050	43.202	43.240	43.279	43.317	43.356	43.394	43.432	43.471	43.509	43.547	43.585	1050
1060	43.585	43.624	43.662	43.700	43.739	43.777	43.815	43.853	43.891	43.930	43.968	1060
1070	43.968	44.006	44.044	44.082	44.121	44.159	44.197	44.235	44.273	44.311	44.349	1070
1080	44.349	44.387	44.425	44.463	44.501	44.539	44.577	44.615	44.653	44.691	44.729	1080
1090	44.729	44.767	44.805	44.843	44.881	44.919	44.957	44.995	45.033	45.070	45.108	1090
1100	45.108	45.146	45.184	45.222	45.260	45.297	45.335	45.373	45.411	45.448	45.486	1100
1110	45.486	45.524	45.561	45.599	45.637	45.675	45.712	45.750	45.787	45.825	45.863	1110
1120	45.863	45.900	45.938	45.975	46.013	46.050	46.088	46.126	46.163	46.201	46.238	1120
1130	46.238	46.275	46.313	46.350	46.388	46.425	46.463	46.500	46.537	46.575	46.612	1130
1140	46.612	46.649	46.687	46.724	46.761	46.799	46.836	46.873	46.910	46.948	46.985	1140
1150	46.985	47.022	47.059	47.096	47.134	47.171	47.208	47.245	47.282	47.319	47.356	1150
1160	47.356	47.393	47.430	47.468	47.505	47.542	47.579	47.616	47.653	47.689	47.726	1160
1170	47.726	47.763	47.800	47.837	47.874	47.911	47.948	47.985	48.021	48.058	48.095	1170
1180	48.095	48.132	48.169	48.205	48.242	48.279	48.316	48.352	48.389	48.426	48.462	1180
1190	48.462	48.499	48.536	48.572	48.609	48.645	48.682	48.718	48.755	48.792	48.828	1190
1200	48.828	48.865	48.901	48.937	48.974	49.010	49.047	49.083	49.120	49.156	49.192	1200
1210	49.192	49.229	49.265	49.301	49.338	49.374	49.410	49.446	49.483	49.519	49.555	1210
DEG C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DEG C**

Table 14 (continued) — Temperature-EMF for type K thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
						THERMOELECTRIC VOLTAGE IN MILLIVOLTS						
1220	49.555	49.591	49.627	49.663	49.700	49.736	49.772	49.808	49.844	49.880	49.916	1220
1230	49.916	49.952	49.988	50.024	50.060	50.096	50.132	50.168	50.204	50.240	50.276	1230
1240	50.276	50.311	50.347	50.383	50.419	50.455	50.491	50.526	50.562	50.598	50.633	1240
1250	50.633	50.669	50.705	50.741	50.776	50.812	50.847	50.883	50.919	50.954	50.990	1250
1260	50.990	51.025	51.061	51.096	51.132	51.167	51.203	51.238	51.274	51.309	51.344	1260
1270	51.344	51.380	51.415	51.450	51.486	51.521	51.556	51.592	51.627	51.662	51.697	1270
1280	51.697	51.733	51.768	51.803	51.838	51.873	51.908	51.943	51.979	52.014	52.049	1280
1290	52.049	52.084	52.119	52.154	52.189	52.224	52.259	52.294	52.329	52.364	52.398	1290
1300	52.398	52.433	52.468	52.503	52.538	52.573	52.608	52.642	52.677	52.712	52.747	1300
1310	52.747	52.781	52.816	52.851	52.886	52.920	52.955	52.989	53.024	53.059	53.093	1310
1320	53.093	53.128	53.162	53.197	53.232	53.266	53.301	53.335	53.370	53.404	53.439	1320
1330	53.439	53.473	53.507	53.542	53.576	53.611	53.645	53.679	53.714	53.748	53.782	1330
1340	53.782	53.817	53.851	53.885	53.920	53.954	53.988	54.022	54.057	54.091	54.125	1340
1350	54.125	54.159	54.193	54.228	54.262	54.296	54.330	54.364	54.398	54.432	54.466	1350
1360	54.466	54.501	54.535	54.569	54.603	54.637	54.671	54.705	54.739	54.773	54.807	1360
1370	54.807	54.841	54.875									1370
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 15 — Temperature-EMF for type R thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

THERMOELECTRIC VOLTAGE IN MILLIVOLTS

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
–50	–0.226											–50
–40	–0.188	–0.192	–0.196	–0.200	–0.204	–0.207	–0.211	–0.215	–0.219	–0.223	–0.226	–40
–30	–0.145	–0.150	–0.154	–0.158	–0.163	–0.167	–0.171	–0.175	–0.180	–0.184	–0.188	–30
–20	–0.100	–0.105	–0.109	–0.114	–0.119	–0.123	–0.128	–0.132	–0.137	–0.141	–0.145	–20
–10	–0.051	–0.056	–0.061	–0.066	–0.071	–0.076	–0.081	–0.086	–0.091	–0.095	–0.100	–10
–0	0.000	–0.005	–0.011	–0.016	–0.021	–0.026	–0.031	–0.036	–0.041	–0.046	–0.051	–0
0	0.000	0.005	0.011	0.016	0.021	0.027	0.032	0.038	0.043	0.049	0.054	0
10	0.054	0.060	0.065	0.071	0.077	0.082	0.088	0.094	0.100	0.105	0.111	10
20	0.111	0.117	0.123	0.129	0.135	0.141	0.147	0.152	0.158	0.165	0.171	20
30	0.171	0.177	0.183	0.189	0.195	0.201	0.207	0.214	0.220	0.226	0.232	30
40	0.232	0.239	0.245	0.251	0.258	0.264	0.271	0.277	0.283	0.290	0.296	40
50	0.296	0.303	0.310	0.316	0.323	0.329	0.336	0.343	0.349	0.356	0.363	50
60	0.363	0.369	0.376	0.383	0.390	0.397	0.403	0.410	0.417	0.424	0.431	60
70	0.431	0.438	0.445	0.452	0.459	0.466	0.473	0.480	0.487	0.494	0.501	70
80	0.501	0.508	0.515	0.523	0.530	0.537	0.544	0.552	0.559	0.566	0.573	80
90	0.573	0.581	0.588	0.595	0.603	0.610	0.617	0.625	0.632	0.640	0.647	90
100	0.647	0.655	0.662	0.670	0.677	0.685	0.692	0.700	0.708	0.715	0.723	100
110	0.723	0.730	0.738	0.746	0.754	0.761	0.769	0.777	0.784	0.792	0.800	110
120	0.800	0.808	0.816	0.824	0.831	0.839	0.847	0.855	0.863	0.871	0.879	120
130	0.879	0.887	0.895	0.903	0.911	0.919	0.927	0.935	0.943	0.951	0.959	130
140	0.959	0.967	0.975	0.983	0.992	1.000	1.008	1.016	1.024	1.032	1.041	140
150	1.041	1.049	1.057	1.065	1.074	1.082	1.090	1.099	1.107	1.115	1.124	150
160	1.124	1.132	1.140	1.149	1.157	1.166	1.174	1.183	1.191	1.200	1.208	160
170	1.208	1.217	1.225	1.234	1.242	1.251	1.259	1.268	1.276	1.285	1.294	170
180	1.294	1.302	1.311	1.319	1.328	1.337	1.345	1.354	1.363	1.372	1.380	180
190	1.380	1.389	1.398	1.407	1.415	1.424	1.433	1.442	1.450	1.459	1.468	190
200	1.468	1.477	1.486	1.495	1.504	1.512	1.521	1.530	1.539	1.548	1.557	200
210	1.557	1.566	1.575	1.584	1.593	1.602	1.611	1.620	1.629	1.638	1.647	210
220	1.647	1.656	1.665	1.674	1.683	1.692	1.702	1.711	1.720	1.729	1.738	220
230	1.738	1.747	1.756	1.766	1.775	1.784	1.793	1.802	1.812	1.821	1.830	230
240	1.830	1.839	1.849	1.858	1.867	1.876	1.886	1.895	1.904	1.914	1.923	240
250	1.923	1.932	1.942	1.951	1.960	1.970	1.979	1.988	1.998	2.007	2.017	250
260	2.017	2.026	2.036	2.045	2.054	2.064	2.073	2.083	2.092	2.102	2.111	260
270	2.111	2.121	2.130	2.140	2.149	2.159	2.169	2.178	2.188	2.197	2.207	270
280	2.207	2.216	2.226	2.236	2.245	2.255	2.264	2.274	2.284	2.293	2.303	280
290	2.303	2.313	2.322	2.332	2.342	2.351	2.361	2.371	2.381	2.390	2.400	290
300	2.400	2.410	2.420	2.429	2.439	2.449	2.459	2.468	2.478	2.488	2.498	300
310	2.498	2.508	2.517	2.527	2.537	2.547	2.557	2.567	2.577	2.586	2.596	310
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 15 (continued) — Temperature-EMF for type R thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
						THERMOELECTRIC VOLTAGE IN MILLIVOLTS						
320	2.596	2.606	2.616	2.626	2.636	2.646	2.656	2.666	2.676	2.685	2.695	320
330	2.695	2.705	2.715	2.725	2.735	2.745	2.755	2.765	2.775	2.785	2.795	330
340	2.795	2.805	2.815	2.825	2.835	2.845	2.855	2.866	2.876	2.886	2.896	340
350	2.896	2.906	2.916	2.926	2.936	2.946	2.956	2.966	2.977	2.987	2.997	350
360	2.997	3.007	3.017	3.027	3.037	3.048	3.058	3.068	3.078	3.088	3.099	360
370	3.099	3.109	3.119	3.129	3.139	3.150	3.160	3.170	3.180	3.191	3.201	370
380	3.201	3.211	3.221	3.232	3.242	3.252	3.263	3.273	3.283	3.293	3.304	380
390	3.304	3.314	3.324	3.335	3.345	3.355	3.366	3.376	3.386	3.397	3.407	390
400	3.407	3.418	3.428	3.438	3.449	3.459	3.470	3.480	3.490	3.501	3.511	400
410	3.511	3.522	3.532	3.542	3.553	3.563	3.574	3.584	3.595	3.605	3.616	410
420	3.616	3.626	3.637	3.647	3.658	3.668	3.679	3.689	3.700	3.710	3.721	420
430	3.721	3.731	3.742	3.752	3.763	3.774	3.784	3.795	3.805	3.816	3.826	430
440	3.826	3.837	3.848	3.858	3.869	3.879	3.890	3.901	3.911	3.922	3.933	440
450	3.933	3.943	3.954	3.964	3.975	3.986	3.996	4.007	4.018	4.028	4.039	450
460	4.039	4.050	4.061	4.071	4.082	4.093	4.103	4.114	4.125	4.136	4.146	460
470	4.146	4.157	4.168	4.178	4.189	4.200	4.211	4.222	4.232	4.243	4.254	470
480	4.254	4.265	4.275	4.286	4.297	4.308	4.319	4.329	4.340	4.351	4.362	480
490	4.362	4.373	4.384	4.394	4.405	4.416	4.427	4.438	4.449	4.460	4.471	490
500	4.471	4.481	4.492	4.503	4.514	4.525	4.536	4.547	4.558	4.569	4.580	500
510	4.580	4.591	4.601	4.612	4.623	4.634	4.645	4.656	4.667	4.678	4.689	510
520	4.689	4.700	4.711	4.722	4.733	4.744	4.755	4.766	4.777	4.788	4.799	520
530	4.799	4.810	4.821	4.832	4.843	4.854	4.865	4.876	4.888	4.899	4.910	530
540	4.910	4.921	4.932	4.943	4.954	4.965	4.976	4.987	4.998	5.009	5.021	540
550	5.021	5.032	5.043	5.054	5.065	5.076	5.087	5.099	5.110	5.121	5.132	550
560	5.132	5.143	5.154	5.166	5.177	5.188	5.199	5.210	5.221	5.233	5.244	560
570	5.244	5.255	5.266	5.278	5.289	5.300	5.311	5.322	5.334	5.345	5.356	570
580	5.356	5.367	5.379	5.390	5.401	5.413	5.424	5.435	5.446	5.458	5.469	580
590	5.469	5.480	5.492	5.503	5.514	5.526	5.537	5.548	5.560	5.571	5.582	590
600	5.582	5.594	5.605	5.616	5.628	5.639	5.650	5.662	5.673	5.685	5.696	600
610	5.696	5.707	5.719	5.730	5.742	5.753	5.764	5.776	5.787	5.799	5.810	610
620	5.810	5.821	5.833	5.844	5.856	5.867	5.879	5.890	5.902	5.913	5.925	620
630	5.925	5.936	5.948	5.959	5.971	5.982	5.994	6.005	6.017	6.028	6.040	630
640	6.040	6.051	6.063	6.074	6.086	6.098	6.109	6.121	6.132	6.144	6.155	640
650	6.155	6.167	6.179	6.190	6.202	6.213	6.225	6.237	6.248	6.260	6.272	650
660	6.272	6.283	6.295	6.307	6.318	6.330	6.342	6.353	6.365	6.377	6.388	660
670	6.388	6.400	6.412	6.423	6.435	6.447	6.458	6.470	6.482	6.494	6.505	670
680	6.505	6.517	6.529	6.541	6.552	6.564	6.576	6.588	6.599	6.611	6.623	680
690	6.623	6.635	6.647	6.658	6.670	6.682	6.694	6.706	6.718	6.729	6.741	690
DEG C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DEG C**

Table 15 (continued) — Temperature-EMF for type R thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

THERMOELECTRIC VOLTAGE IN MILLIVOLTS

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
700	6.741	6.753	6.765	6.777	6.789	6.800	6.812	6.824	6.836	6.848	6.860	700
710	6.860	6.872	6.884	6.895	6.907	6.919	6.931	6.943	6.955	6.967	6.979	710
720	6.979	6.991	7.003	7.015	7.027	7.039	7.051	7.063	7.074	7.086	7.098	720
730	7.098	7.110	7.122	7.134	7.146	7.158	7.170	7.182	7.194	7.206	7.218	730
740	7.218	7.231	7.243	7.255	7.267	7.279	7.291	7.303	7.315	7.327	7.339	740
750	7.339	7.351	7.363	7.375	7.387	7.399	7.412	7.424	7.436	7.448	7.460	750
760	7.460	7.472	7.484	7.496	7.509	7.521	7.533	7.545	7.557	7.569	7.582	760
770	7.582	7.594	7.606	7.618	7.630	7.642	7.655	7.667	7.679	7.691	7.703	770
780	7.703	7.716	7.728	7.740	7.752	7.765	7.777	7.789	7.801	7.814	7.826	780
790	7.826	7.838	7.850	7.863	7.875	7.887	7.900	7.912	7.924	7.937	7.949	790
800	7.949	7.961	7.973	7.986	7.998	8.010	8.023	8.035	8.047	8.060	8.072	800
810	8.072	8.085	8.097	8.109	8.122	8.134	8.146	8.159	8.171	8.184	8.196	810
820	8.196	8.208	8.221	8.233	8.246	8.258	8.271	8.283	8.295	8.308	8.320	820
830	8.320	8.333	8.345	8.358	8.370	8.383	8.395	8.408	8.420	8.433	8.445	830
840	8.445	8.458	8.470	8.483	8.495	8.508	8.520	8.533	8.545	8.558	8.570	840
850	8.570	8.583	8.595	8.608	8.621	8.633	8.646	8.658	8.671	8.683	8.696	850
860	8.696	8.709	8.721	8.734	8.746	8.759	8.772	8.784	8.797	8.810	8.822	860
870	8.822	8.835	8.847	8.860	8.873	8.885	8.898	8.911	8.923	8.936	8.949	870
880	8.949	8.961	8.974	8.987	9.000	9.012	9.025	9.038	9.050	9.063	9.076	880
890	9.076	9.089	9.101	9.114	9.127	9.140	9.152	9.165	9.178	9.191	9.203	890
900	9.203	9.216	9.229	9.242	9.254	9.267	9.280	9.293	9.306	9.319	9.331	900
910	9.331	9.344	9.357	9.370	9.383	9.395	9.408	9.421	9.434	9.447	9.460	910
920	9.460	9.473	9.485	9.498	9.511	9.524	9.537	9.550	9.563	9.576	9.589	920
930	9.589	9.602	9.614	9.627	9.640	9.653	9.666	9.679	9.692	9.705	9.718	930
940	9.718	9.731	9.744	9.757	9.770	9.783	9.796	9.809	9.822	9.835	9.848	940
950	9.848	9.861	9.874	9.887	9.900	9.913	9.926	9.939	9.952	9.965	9.978	950
960	9.978	9.991	10.004	10.017	10.030	10.043	10.056	10.069	10.082	10.095	10.109	960
970	10.109	10.122	10.135	10.148	10.161	10.174	10.187	10.200	10.213	10.227	10.240	970
980	10.240	10.253	10.266	10.279	10.292	10.305	10.319	10.332	10.345	10.358	10.371	980
990	10.371	10.384	10.398	10.411	10.424	10.437	10.450	10.464	10.477	10.490	10.503	990
1000	10.503	10.516	10.530	10.543	10.556	10.569	10.583	10.596	10.609	10.622	10.636	1000
1010	10.636	10.649	10.662	10.675	10.689	10.702	10.715	10.729	10.742	10.755	10.768	1010
1020	10.768	10.782	10.795	10.808	10.822	10.835	10.848	10.862	10.875	10.888	10.902	1020
1030	10.902	10.915	10.928	10.942	10.955	10.968	10.982	10.995	11.009	11.022	11.035	1030
1040	11.035	11.049	11.062	11.076	11.089	11.102	11.116	11.129	11.143	11.156	11.170	1040
1050	11.170	11.183	11.196	11.210	11.223	11.237	11.250	11.264	11.277	11.291	11.304	1050
1060	11.304	11.318	11.331	11.345	11.358	11.372	11.385	11.399	11.412	11.426	11.439	1060
1070	11.439	11.453	11.466	11.480	11.493	11.507	11.520	11.534	11.547	11.561	11.574	1070
1080	11.574	11.588	11.602	11.615	11.629	11.642	11.656	11.669	11.683	11.697	11.710	1080
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 15 (continued) — Temperature-EMF for type R thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
						THERMOELECTRIC VOLTAGE IN MILLIVOLTS						
1090	11.710	11.724	11.737	11.751	11.765	11.778	11.792	11.805	11.819	11.833	11.846	1090
1100	11.846	11.860	11.874	11.887	11.901	11.914	11.928	11.942	11.955	11.969	11.983	1100
1110	11.983	11.996	12.010	12.024	12.037	12.051	12.065	12.078	12.092	12.106	12.119	1110
1120	12.119	12.133	12.147	12.161	12.174	12.188	12.202	12.215	12.229	12.243	12.257	1120
1130	12.257	12.270	12.284	12.298	12.311	12.325	12.339	12.353	12.366	12.380	12.394	1130
1140	12.394	12.408	12.421	12.435	12.449	12.463	12.476	12.490	12.504	12.518	12.532	1140
1150	12.532	12.545	12.559	12.573	12.587	12.600	12.614	12.628	12.642	12.656	12.669	1150
1160	12.669	12.683	12.697	12.711	12.725	12.739	12.752	12.766	12.780	12.794	12.808	1160
1170	12.808	12.822	12.835	12.849	12.863	12.877	12.891	12.905	12.918	12.932	12.946	1170
1180	12.946	12.960	12.974	12.988	13.002	13.016	13.029	13.043	13.057	13.071	13.085	1180
1190	13.085	13.099	13.113	13.127	13.140	13.154	13.168	13.182	13.196	13.210	13.224	1190
1200	13.224	13.238	13.252	13.266	13.280	13.293	13.307	13.321	13.335	13.349	13.363	1200
1210	13.363	13.377	13.391	13.405	13.419	13.433	13.447	13.461	13.475	13.489	13.502	1210
1220	13.502	13.516	13.530	13.544	13.558	13.572	13.586	13.600	13.614	13.628	13.642	1220
1230	13.642	13.656	13.670	13.684	13.698	13.712	13.726	13.740	13.754	13.768	13.782	1230
1240	13.782	13.796	13.810	13.824	13.838	13.852	13.866	13.880	13.894	13.908	13.922	1240
1250	13.922	13.936	13.950	13.964	13.978	13.992	14.006	14.020	14.034	14.048	14.062	1250
1260	14.062	14.076	14.090	14.104	14.118	14.132	14.146	14.160	14.174	14.188	14.202	1260
1270	14.202	14.216	14.230	14.244	14.258	14.272	14.286	14.301	14.315	14.329	14.343	1270
1280	14.343	14.357	14.371	14.385	14.399	14.413	14.427	14.441	14.455	14.469	14.483	1280
1290	14.483	14.497	14.511	14.525	14.539	14.554	14.568	14.582	14.596	14.610	14.624	1290
1300	14.624	14.638	14.652	14.666	14.680	14.694	14.708	14.722	14.737	14.751	14.765	1300
1310	14.765	14.779	14.793	14.807	14.821	14.835	14.849	14.863	14.877	14.891	14.906	1310
1320	14.906	14.920	14.934	14.948	14.962	14.976	14.990	15.004	15.018	15.032	15.047	1320
1330	15.047	15.061	15.075	15.089	15.103	15.117	15.131	15.145	15.159	15.173	15.188	1330
1340	15.188	15.202	15.216	15.230	15.244	15.258	15.272	15.286	15.300	15.315	15.329	1340
1350	15.329	15.343	15.357	15.371	15.385	15.399	15.413	15.427	15.442	15.456	15.470	1350
1360	15.470	15.484	15.498	15.512	15.526	15.540	15.555	15.569	15.583	15.597	15.611	1360
1370	15.611	15.625	15.639	15.653	15.667	15.682	15.696	15.710	15.724	15.738	15.752	1370
1380	15.752	15.766	15.780	15.795	15.809	15.823	15.837	15.851	15.865	15.879	15.893	1380
1390	15.893	15.908	15.922	15.936	15.950	15.964	15.978	15.992	16.006	16.021	16.035	1390
1400	16.035	16.049	16.063	16.077	16.091	16.105	16.119	16.134	16.148	16.162	16.176	1400
1410	16.176	16.190	16.204	16.218	16.232	16.247	16.261	16.275	16.289	16.303	16.317	1410
1420	16.317	16.331	16.345	16.360	16.374	16.388	16.402	16.416	16.430	16.444	16.458	1420
1430	16.458	16.472	16.487	16.501	16.515	16.529	16.543	16.557	16.571	16.585	16.599	1430
1440	16.599	16.614	16.628	16.642	16.656	16.670	16.684	16.698	16.712	16.726	16.741	1440
1450	16.741	16.755	16.769	16.783	16.797	16.811	16.825	16.839	16.853	16.867	16.882	1450
1460	16.882	16.896	16.910	16.924	16.938	16.952	16.966	16.980	16.994	17.008	17.022	1460
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 15 (continued) — Temperature-EMF for type R thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

THERMOELECTRIC VOLTAGE IN MILLIVOLTS

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
1470	17.022	17.037	17.051	17.065	17.079	17.093	17.107	17.121	17.135	17.149	17.163	1470
1480	17.163	17.177	17.192	17.206	17.220	17.234	17.248	17.262	17.276	17.290	17.304	1480
1490	17.304	17.318	17.332	17.346	17.360	17.374	17.388	17.403	17.417	17.431	17.445	1490
1500	17.445	17.459	17.473	17.487	17.501	17.515	17.529	17.543	17.557	17.571	17.585	1500
1510	17.585	17.599	17.613	17.627	17.641	17.655	17.669	17.684	17.698	17.712	17.726	1510
1520	17.726	17.740	17.754	17.768	17.782	17.796	17.810	17.824	17.838	17.852	17.866	1520
1530	17.866	17.880	17.894	17.908	17.922	17.936	17.950	17.964	17.978	17.992	18.006	1530
1540	18.006	18.020	18.034	18.048	18.062	18.076	18.090	18.104	18.118	18.132	18.146	1540
1550	18.146	18.160	18.174	18.188	18.202	18.216	18.230	18.244	18.258	18.272	18.286	1550
1560	18.286	18.299	18.313	18.327	18.341	18.355	18.369	18.383	18.397	18.411	18.425	1560
1570	18.425	18.439	18.453	18.467	18.481	18.495	18.509	15.523	18.537	18.550	18.564	1570
1580	18.564	18.578	18.592	18.606	18.620	18.634	18.648	18.662	18.676	18.690	18.703	1580
1590	18.703	18.717	18.731	18.745	18.759	18.773	18.787	18.801	18.815	18.828	18.842	1590
1600	18.842	18.856	18.870	18.884	18.898	18.912	18.926	18.939	18.953	18.967	18.981	1600
1610	18.981	18.995	19.009	19.023	19.036	19.050	19.064	19.078	19.092	19.106	19.119	1610
1620	19.119	19.133	19.147	19.161	19.175	19.188	19.202	19.216	19.230	19.244	19.257	1620
1630	19.257	19.271	19.285	19.299	19.313	19.326	19.340	19.354	19.368	19.382	19.395	1630
1640	19.395	19.409	19.423	19.437	19.450	19.464	19.478	19.492	19.505	19.519	19.533	1640
1650	19.533	19.547	19.560	19.574	19.588	19.602	19.615	19.629	19.643	19.656	19.670	1650
1660	19.670	19.684	19.698	19.711	19.725	19.739	19.752	19.766	19.780	19.793	19.807	1660
1670	19.807	19.821	19.834	19.848	19.862	19.875	19.889	19.903	19.916	19.930	19.944	1670
1680	19.944	19.957	19.971	19.985	19.998	20.012	20.025	20.039	20.053	20.066	20.080	1680
1690	20.080	20.093	20.107	20.120	20.134	20.148	20.161	20.175	20.188	20.202	20.215	1690
1700	20.215	20.229	20.242	20.256	20.269	20.283	20.296	20.309	20.323	20.336	20.350	1700
1710	20.350	20.363	20.377	20.390	20.403	20.417	20.430	20.443	20.457	20.470	20.483	1710
1720	20.483	20.497	20.510	20.523	20.537	20.550	20.563	20.576	20.590	20.603	20.616	1720
1730	20.616	20.629	20.642	20.656	20.669	20.682	20.695	20.708	20.721	20.734	20.748	1730
1740	20.748	20.761	20.774	20.787	20.800	20.813	20.826	20.839	20.852	20.865	20.878	1740
1750	20.878	20.891	20.904	20.916	20.929	20.942	20.955	20.968	20.981	20.994	21.006	1750
1760	21.006	21.019	21.032	21.045	21.057	21.070	21.083	21.096	21.108			1760
DEG C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DEG C**

Table 16 — Temperature-EMF for Type S thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
						THERMOELECTRIC VOLTAGE IN MILLIVOLTS						
–50	–0.236											–50
–40	–0.194	–0.199	–0.203	–0.207	–0.211	–0.215	–0.220	–0.224	–0.228	–0.232	–0.236	–40
–30	–0.150	–0.155	–0.159	–0.164	–0.168	–0.173	–0.177	–0.181	–0.186	–0.190	–0.194	–30
–20	–0.103	–0.108	–0.112	–0.117	–0.122	–0.127	–0.132	–0.136	–0.141	–0.145	–0.150	–20
–10	–0.053	–0.058	–0.063	–0.068	–0.073	–0.078	–0.083	–0.088	–0.093	–0.098	–0.103	–10
–0	0.000	–0.005	–0.011	–0.016	–0.021	–0.027	–0.032	–0.037	–0.042	–0.048	–0.053	–0
0	0.000	0.005	0.011	0.016	0.022	0.027	0.033	0.038	0.044	0.050	0.055	0
10	0.055	0.061	0.067	0.072	0.078	0.084	0.090	0.095	0.101	0.107	0.113	10
20	0.113	0.119	0.125	0.131	0.137	0.142	0.148	0.154	0.161	0.167	0.173	20
30	0.173	0.179	0.185	0.191	0.197	0.203	0.210	0.216	0.222	0.228	0.235	30
40	0.235	0.241	0.247	0.254	0.260	0.266	0.273	0.279	0.286	0.292	0.299	40
50	0.299	0.305	0.312	0.318	0.325	0.331	0.338	0.345	0.351	0.358	0.365	50
60	0.365	0.371	0.378	0.385	0.391	0.398	0.405	0.412	0.419	0.425	0.432	60
70	0.432	0.439	0.446	0.453	0.460	0.467	0.474	0.481	0.488	0.495	0.502	70
80	0.502	0.509	0.516	0.523	0.530	0.537	0.544	0.551	0.558	0.566	0.573	80
90	0.573	0.580	0.587	0.594	0.602	0.609	0.616	0.623	0.631	0.638	0.645	90
100	0.645	0.653	0.660	0.667	0.675	0.682	0.690	0.697	0.704	0.712	0.719	100
110	0.719	0.727	0.734	0.742	0.749	0.757	0.764	0.772	0.780	0.787	0.795	110
120	0.795	0.802	0.810	0.818	0.825	0.833	0.841	0.848	0.856	0.864	0.872	120
130	0.872	0.879	0.887	0.895	0.903	0.910	0.918	0.926	0.934	0.942	0.950	130
140	0.950	0.957	0.965	0.973	0.981	0.989	0.997	1.005	1.013	1.021	1.029	140
150	1.029	1.037	1.045	1.053	1.061	1.069	1.077	1.085	1.093	1.101	1.109	150
160	1.109	1.117	1.125	1.133	1.141	1.149	1.158	1.166	1.174	1.182	1.190	160
170	1.190	1.198	1.207	1.215	1.223	1.231	1.240	1.248	1.256	1.264	1.273	170
180	1.273	1.281	1.289	1.297	1.306	1.314	1.322	1.331	1.339	1.347	1.356	180
190	1.356	1.364	1.373	1.381	1.389	1.398	1.406	1.415	1.423	1.432	1.440	190
200	1.440	1.448	1.457	1.465	1.474	1.482	1.491	1.499	1.508	1.516	1.525	200
210	1.525	1.534	1.542	1.551	1.559	1.568	1.576	1.585	1.594	1.602	1.611	210
220	1.611	1.620	1.628	1.637	1.645	1.654	1.663	1.671	1.680	1.689	1.698	220
230	1.698	1.706	1.715	1.724	1.732	1.741	1.750	1.759	1.767	1.776	1.785	230
240	1.785	1.794	1.802	1.811	1.820	1.829	1.838	1.846	1.855	1.864	1.873	240
250	1.873	1.882	1.891	1.899	1.908	1.917	1.926	1.935	1.944	1.953	1.962	250
260	1.962	1.971	1.979	1.988	1.997	2.006	2.015	2.024	2.033	2.042	2.051	260
270	2.051	2.060	2.069	2.078	2.087	2.096	2.105	2.114	2.123	2.132	2.141	270
280	2.141	2.150	2.159	2.168	2.177	2.186	2.195	2.204	2.213	2.222	2.232	280
290	2.232	2.241	2.250	2.259	2.268	2.277	2.286	2.295	2.304	2.314	2.323	290
300	2.323	2.332	2.341	2.350	2.359	2.368	2.378	2.387	2.396	2.405	2.414	300
310	2.414	2.424	2.433	2.442	2.451	2.460	2.470	2.479	2.488	2.497	2.506	310
DEG C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DEG C**

Table 16 (continued) — Temperature-EMF for type S thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
						THERMOELECTRIC VOLTAGE IN MILLIVOLTS						
320	2.506	2.516	2.525	2.534	2.543	2.553	2.562	2.571	2.581	2.590	2.599	320
330	2.599	2.608	2.618	2.627	2.636	2.646	2.655	2.664	2.674	2.683	2.692	330
340	2.692	2.702	2.711	2.720	2.730	2.739	2.748	2.758	2.767	2.776	2.786	340
350	2.786	2.795	2.805	2.814	2.823	2.833	2.842	2.852	2.861	2.870	2.880	350
360	2.880	2.889	2.899	2.908	2.917	2.927	2.936	2.946	2.955	2.965	2.974	360
370	2.974	2.984	2.993	3.003	3.012	3.022	3.031	3.041	3.050	3.059	3.069	370
380	3.069	3.078	3.088	3.097	3.107	3.117	3.126	3.136	3.145	3.155	3.164	380
390	3.164	3.174	3.183	3.193	3.202	3.212	3.221	3.231	3.241	3.250	3.260	390
400	3.260	3.269	3.279	3.288	3.298	3.308	3.317	3.327	3.336	3.346	3.356	400
410	3.356	3.365	3.375	3.384	3.394	3.404	3.413	3.423	3.433	3.442	3.452	410
420	3.452	3.462	3.471	3.481	3.491	3.500	3.510	3.520	3.529	3.539	3.549	420
430	3.549	3.558	3.568	3.578	3.587	3.597	3.607	3.616	3.626	3.636	3.645	430
440	3.645	3.655	3.665	3.675	3.684	3.694	3.704	3.714	3.723	3.733	3.743	440
450	3.743	3.752	3.762	3.772	3.782	3.791	3.801	3.811	3.821	3.831	3.840	450
460	3.840	3.850	3.860	3.870	3.879	3.889	3.899	3.909	3.919	3.928	3.938	460
470	3.938	3.948	3.958	3.968	3.977	3.987	3.997	4.007	4.017	4.027	4.036	470
480	4.036	4.046	4.056	4.066	4.076	4.086	4.095	4.105	4.115	4.125	4.135	480
490	4.135	4.145	4.155	4.164	4.174	4.184	4.194	4.204	4.214	4.224	4.234	490
500	4.234	4.243	4.253	4.263	4.273	4.283	4.293	4.303	4.313	4.323	4.333	500
510	4.333	4.343	4.352	4.362	4.372	4.382	4.392	4.402	4.412	4.422	4.432	510
520	4.432	4.442	4.452	4.462	4.472	4.482	4.492	4.502	4.512	4.522	4.532	520
530	4.532	4.542	4.552	4.562	4.572	4.582	4.592	4.602	4.612	4.622	4.632	530
540	4.632	4.642	4.652	4.662	4.672	4.682	4.692	4.702	4.712	4.722	4.732	540
550	4.732	4.742	4.752	4.762	4.772	4.782	4.792	4.802	4.812	4.822	4.832	550
560	4.832	4.842	4.852	4.862	4.873	4.883	4.893	4.903	4.913	4.923	4.933	560
570	4.933	4.943	4.953	4.963	4.973	4.984	4.994	5.004	5.014	5.024	5.034	570
580	5.034	5.044	5.054	5.065	5.075	5.085	5.095	5.105	5.115	5.125	5.136	580
590	5.136	5.146	5.156	5.166	5.176	5.186	5.197	5.207	5.217	5.227	5.237	590
600	5.237	5.247	5.258	5.268	5.278	5.288	5.298	5.309	5.319	5.329	5.339	600
610	5.339	5.350	5.360	5.370	5.380	5.391	5.401	5.411	5.421	5.431	5.442	610
620	5.442	5.452	5.462	5.473	5.483	5.493	5.503	5.514	5.524	5.534	5.544	620
630	5.544	5.555	5.565	5.575	5.586	5.596	5.606	5.617	5.627	5.637	5.648	630
640	5.648	5.658	5.668	5.679	5.689	5.700	5.710	5.720	5.731	5.741	5.751	640
650	5.751	5.762	5.772	5.782	5.793	5.803	5.814	5.824	5.834	5.845	5.855	650
660	5.855	5.866	5.876	5.887	5.897	5.907	5.918	5.928	5.939	5.949	5.960	660
670	5.960	5.970	5.980	5.991	6.001	6.012	6.022	6.033	6.043	6.054	6.064	670
680	6.064	6.075	6.085	6.096	6.106	6.117	6.127	6.138	6.148	6.159	6.169	680
690	6.169	6.180	6.190	6.201	6.211	6.222	6.232	6.243	6.253	6.264	6.274	690
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 16 (continued) — Temperature-EMF for type S thermocouples

Temperatures in degrees Celsius (IPTS-68)   Reference junctions at 0°C

THERMOELECTRIC VOLTAGE IN MILLIVOLTS

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
700	6.274	6.285	6.295	6.306	6.316	6.327	6.338	6.348	6.359	6.369	6.380	700
710	6.380	6.390	6.401	6.412	6.422	6.433	6.443	6.454	6.465	6.475	6.486	710
720	6.486	6.496	6.507	6.518	6.528	6.539	6.549	6.560	6.571	6.581	6.592	720
730	6.592	6.603	6.613	6.624	6.635	6.645	6.656	6.667	6.677	6.688	6.699	730
740	6.699	6.709	6.720	6.731	6.741	6.752	6.763	6.773	6.784	6.795	6.805	740
750	6.805	6.816	6.827	6.838	6.848	6.859	6.870	6.880	6.891	6.902	6.913	750
760	6.913	6.923	6.934	6.945	6.956	6.966	6.977	6.988	6.999	7.009	7.020	760
770	7.020	7.031	7.042	7.053	7.063	7.074	7.085	7.096	7.107	7.117	7.128	770
780	7.128	7.139	7.150	7.161	7.171	7.182	7.193	7.204	7.215	7.225	7.236	780
790	7.236	7.247	7.258	7.269	7.280	7.291	7.301	7.312	7.323	7.334	7.345	790
800	7.345	7.356	7.367	7.377	7.388	7.399	7.410	7.421	7.432	7.443	7.454	800
810	7.454	7.465	7.476	7.486	7.497	7.508	7.519	7.530	7.541	7.552	7.563	810
820	7.563	7.574	7.585	7.596	7.607	7.618	7.629	7.640	7.651	7.661	7.672	820
830	7.672	7.683	7.694	7.705	7.716	7.727	7.738	7.749	7.760	7.771	7.782	830
840	7.782	7.793	7.804	7.815	7.826	7.837	7.848	7.859	7.870	7.881	7.892	840
850	7.892	7.904	7.915	7.926	7.937	7.948	7.959	7.970	7.981	7.992	8.003	850
860	8.003	8.014	8.025	8.036	8.047	8.058	8.069	8.081	8.092	8.103	8.114	860
870	8.114	8.125	8.136	8.147	8.158	8.169	8.180	8.192	8.203	8.214	8.225	870
880	8.225	8.236	8.247	8.258	8.270	8.281	8.292	8.303	8.314	8.325	8.336	880
890	8.336	8.348	8.359	8.370	8.381	8.392	8.404	8.415	8.426	8.437	8.448	890
900	8.448	8.460	8.471	8.482	8.493	8.504	8.516	8.527	8.538	8.549	8.560	900
910	8.560	8.572	8.583	8.594	8.605	8.617	8.628	8.639	8.650	8.662	8.673	910
920	8.673	8.684	8.695	8.707	8.718	8.729	8.741	8.752	8.763	8.774	8.786	920
930	8.786	8.797	8.808	8.820	8.831	8.842	8.854	8.865	8.876	8.888	8.899	930
940	8.899	8.910	8.922	8.933	8.944	8.956	8.967	8.978	8.990	9.001	9.012	940
950	9.012	9.024	9.035	9.047	9.058	9.069	9.081	9.092	9.103	9.115	9.126	950
960	9.126	9.138	9.149	9.160	9.172	9.183	9.195	9.206	9.217	9.229	9.240	960
970	9.240	9.252	9.263	9.275	9.286	9.298	9.309	9.320	9.332	9.343	9.355	970
980	9.355	9.366	9.378	9.389	9.401	9.412	9.424	9.435	9.447	9.458	9.470	980
990	9.470	9.481	9.493	9.504	9.516	9.527	9.539	9.550	9.562	9.573	9.585	990
1000	9.585	9.596	9.608	9.619	9.631	9.642	9.654	9.665	9.677	9.689	9.700	1000
1010	9.700	9.712	9.723	9.735	9.746	9.758	9.770	9.781	9.793	9.804	9.816	1010
1020	9.816	9.828	9.839	9.851	9.862	9.874	9.886	9.897	9.909	9.920	9.932	1020
1030	9.932	9.944	9.955	9.967	9.979	9.990	10.002	10.013	10.025	10.037	10.048	1030
1040	10.048	10.060	10.072	10.083	10.095	10.107	10.118	10.130	10.142	10.154	10.165	1040
1050	10.165	10.177	10.189	10.200	10.212	10.224	10.235	10.247	10.259	10.271	10.282	1050
1060	10.282	10.294	10.306	10.318	10.329	10.341	10.353	10.364	10.376	10.388	10.400	1060
1070	10.400	10.411	10.423	10.435	10.447	10.459	10.470	10.482	10.494	10.506	10.517	1070
1080	10.517	10.529	10.541	10.553	10.565	10.576	10.588	10.600	10.612	10.624	10.635	1080
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Table 16 (continued) — Temperature-EMF for type S thermocouples

Temperatures in degrees Celsius (IPTS-68)   Reference junctions at 0°C

THERMOELECTRIC VOLTAGE IN MILLIVOLTS

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
1090	10.635	10.647	10.659	10.671	10.683	10.694	10.706	10.718	10.730	10.742	10.754	1090
1100	10.754	10.765	10.777	10.789	10.801	10.813	10.825	10.836	10.848	10.860	10.872	1100
1110	10.872	10.884	10.896	10.908	10.919	10.931	10.943	10.955	10.967	10.979	10.991	1110
1120	10.991	11.003	11.014	11.026	11.038	11.050	11.062	11.074	11.086	11.098	11.110	1120
1130	11.110	11.121	11.133	11.145	11.157	11.169	11.181	11.193	11.205	11.217	11.229	1130
1140	11.229	11.241	11.252	11.264	11.276	11.288	11.300	11.312	11.324	11.336	11.348	1140
1150	11.348	11.360	11.372	11.384	11.396	11.408	11.420	11.432	11.443	11.455	11.467	1150
1160	11.467	11.479	11.491	11.503	11.515	11.527	11.539	11.551	11.563	11.575	11.587	1160
1170	11.587	11.599	11.611	11.623	11.635	11.647	11.659	11.671	11.683	11.695	11.707	1170
1180	11.707	11.719	11.731	11.743	11.755	11.767	11.779	11.791	11.803	11.815	11.827	1180
1190	11.827	11.839	11.851	11.863	11.875	11.887	11.899	11.911	11.923	11.935	11.947	1190
1200	11.947	11.959	11.971	11.983	11.995	12.007	12.019	12.031	12.043	12.055	12.067	1200
1210	12.067	12.079	12.091	12.103	12.116	12.128	12.140	12.152	12.164	12.176	12.188	1210
1220	12.188	12.200	12.212	12.224	12.236	12.248	12.260	12.272	12.284	12.296	12.308	1220
1230	12.308	12.320	12.332	12.345	12.357	12.369	12.381	12.393	12.405	12.417	12.429	1230
1240	12.429	12.441	12.453	12.465	12.477	12.489	12.501	12.514	12.526	12.538	12.550	1240
1250	12.550	12.562	12.574	12.586	12.598	12.610	12.622	12.634	12.647	12.659	12.671	1250
1260	12.671	12.683	12.695	12.707	12.719	12.731	12.743	12.755	12.767	12.780	12.792	1260
1270	12.792	12.804	12.816	12.828	12.840	12.852	12.864	12.876	12.888	12.901	12.913	1270
1280	12.913	12.925	12.937	12.949	12.961	12.973	12.985	12.997	13.010	13.022	13.034	1280
1290	13.034	13.046	13.058	13.070	13.082	13.094	13.107	13.119	13.131	13.143	13.155	1290
1300	13.155	13.167	13.179	13.191	13.203	13.216	13.228	13.240	13.252	13.264	13.276	1300
1310	13.276	13.288	13.300	13.313	13.325	13.337	13.349	13.361	13.373	13.385	13.397	1310
1320	13.397	13.410	13.422	13.434	13.446	13.458	13.470	13.482	13.495	13.507	13.519	1320
1330	13.519	13.531	13.543	13.555	13.567	13.579	13.592	13.604	13.616	13.628	13.640	1330
1340	13.640	13.652	13.664	13.677	13.689	13.701	13.713	13.725	13.737	13.749	13.761	1340
1350	13.761	13.774	13.786	13.798	13.810	13.822	13.834	13.846	13.859	13.871	13.883	1350
1360	13.883	13.895	13.907	13.919	13.931	13.943	13.956	13.968	13.980	13.992	14.004	1360
1370	14.004	14.016	14.028	14.040	14.053	14.065	14.077	14.089	14.101	14.113	14.125	1370
1380	14.125	14.138	14.150	14.162	14.174	14.186	14.198	14.210	14.222	14.235	14.247	1380
1390	14.247	14.259	14.271	14.283	14.295	14.307	14.319	14.332	14.344	14.356	14.368	1390
1400	14.368	14.380	14.392	14.404	14.416	14.429	14.441	14.453	14.465	14.477	14.489	1400
1410	14.489	14.501	14.513	14.526	14.538	14.550	14.562	14.574	14.586	14.598	14.610	1410
1420	14.610	14.622	14.635	14.647	14.659	14.671	14.683	14.695	14.707	14.719	14.731	1420
1430	14.731	14.744	14.756	14.768	14.780	14.792	14.804	14.816	14.828	14.840	14.852	1430
1440	14.852	14.865	14.877	14.889	14.901	14.913	14.925	14.937	14.949	14.961	14.973	1440
1450	14.973	14.985	14.998	15.010	15.022	15.034	15.046	15.058	15.070	15.082	15.094	1450
1460	15.094	15.106	15.118	15.130	15.143	15.155	15.167	15.179	15.191	15.203	15.215	1460
DEG C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DEG C**

Table 16 (continued) — Temperature-EMF for type S thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
						THERMOELECTRIC VOLTAGE IN MILLIVOLTS						
1470	15.215	15.227	15.239	15.251	15.263	15.275	15.287	15.299	15.311	15.324	15.336	1470
1480	15.336	15.348	15.360	15.372	15.384	15.396	15.408	15.420	15.432	15.444	15.456	1480
1490	15.456	15.468	15.480	15.492	15.504	15.516	15.528	15.540	15.552	15.564	15.576	1490
1500	15.576	15.589	15.601	15.613	15.625	15.637	15.649	15.661	15.673	15.685	15.697	1500
1510	15.697	15.709	15.721	15.733	15.745	15.757	15.769	15.781	15.793	15.805	15.817	1510
1520	15.817	15.829	15.841	15.853	15.865	15.877	15.889	15.901	15.913	15.925	15.937	1520
1530	15.937	15.949	15.961	15.973	15.985	15.997	16.009	16.021	16.033	16.045	16.057	1530
1540	16.057	16.069	16.080	16.092	16.104	16.116	16.128	16.140	16.152	16.164	16.176	1540
1550	16.176	16.188	16.200	16.212	16.224	16.236	16.248	16.260	16.272	16.284	16.296	1550
1560	16.296	16.308	16.319	16.331	16.343	16.355	16.367	16.379	16.391	16.403	16.415	1560
1570	16.415	16.427	16.439	16.451	16.462	16.474	16.486	16.498	16.510	16.522	16.534	1570
1580	16.534	16.546	16.558	16.569	16.581	16.593	16.605	16.617	16.629	16.641	16.653	1580
1590	16.653	16.664	16.676	16.688	16.700	16.712	16.724	16.736	16.747	16.759	16.771	1590
1600	16.771	16.783	16.795	16.807	16.819	16.830	16.842	16.854	16.866	16.878	16.890	1600
1610	16.890	16.901	16.913	16.925	16.937	16.949	16.960	16.972	16.984	16.996	17.008	1610
1620	17.008	17.019	17.031	17.043	17.055	17.067	17.078	17.090	17.102	17.114	17.125	1620
1630	17.125	17.137	17.149	17.161	17.173	17.184	17.196	17.208	17.220	17.231	17.243	1630
1640	17.243	17.255	17.267	17.278	17.290	17.302	17.313	17.325	17.337	17.349	17.360	1640
1650	17.360	17.372	17.384	17.396	17.407	17.419	17.431	17.442	17.454	17.466	17.477	1650
1660	17.477	17.489	17.501	17.512	17.524	17.536	17.548	17.559	17.571	17.583	17.594	1660
1670	17.594	17.606	17.617	17.629	17.641	17.652	17.664	17.676	17.687	17.699	17.711	1670
1680	17.711	17.722	17.734	17.745	17.757	17.769	17.780	17.792	17.803	17.815	17.826	1680
1690	17.826	17.838	17.850	17.861	17.873	17.884	17.896	17.907	17.919	17.930	17.942	1690
1700	17.942	17.953	17.965	17.976	17.988	17.999	18.010	18.022	18.033	18.045	18.056	1700
1710	18.056	18.068	18.079	18.090	18.102	18.113	18.124	18.136	18.147	18.158	18.170	1710
1720	18.170	18.181	18.192	18.204	18.215	18.226	18.237	18.249	18.260	18.271	18.282	1720
1730	18.282	18.293	18.305	18.316	18.327	18.338	18.349	18.360	18.372	18.383	18.394	1730
1740	18.394	18.405	18.416	18.427	18.438	18.449	18.460	18.471	18.482	18.493	18.504	1740
1750	18.504	18.515	18.526	18.536	18.547	18.558	18.569	18.580	18.591	18.602	18.612	1750
1760	18.612	18.623	18.634	18.645	18.655	18.666	18.677	18.687	18.698			1760
DEG C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DEG C**

Table 17 — Temperature-EMF for type T thermocouples

Temperatures in degrees Celsius (IPTS-68) **Reference junctions at 0°C**

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
						THERMOELECTRIC VOLTAGE IN MILLIVOLTS						
–270	–6.258											–270
–260	–6.232	–6.236	–6.239	–6.242	–6.245	–6.248	–6.251	–6.253	–6.255	–6.256	–6.258	–260
–250	–6.181	–6.187	–6.193	–6.198	–6.204	–6.209	–6.214	–6.219	–6.224	–6.228	–6.232	–250
–240	–6.105	–6.114	–6.122	–6.130	–6.138	–6.146	–6.153	–6.160	–6.167	–6.174	–6.181	–240
–230	–6.007	–6.018	–6.028	–6.039	–6.049	–6.059	–6.068	–6.078	–6.087	–6.096	–6.105	–230
–220	–5.889	–5.901	–5.914	–5.926	–5.938	–5.950	–5.962	–5.973	–5.985	–5.996	–6.007	–220
–210	–5.753	–5.767	–5.782	–5.795	–5.809	–5.823	–5.836	–5.850	–5.863	–5.876	–5.889	–210
–200	–5.603	–5.619	–5.634	–5.650	–5.665	–5.680	–5.695	–5.710	–5.724	–5.739	–5.753	–200
–190	–5.439	–5.456	–5.473	–5.489	–5.506	–5.522	–5.539	–5.555	–5.571	–5.587	–5.603	–190
–180	–5.261	–5.279	–5.297	–5.315	–5.333	–5.351	–5.369	–5.387	–5.404	–5.421	–5.439	–180
–170	–5.069	–5.089	–5.109	–5.128	–5.147	–5.167	–5.186	–5.205	–5.223	–5.242	–5.261	–170
–160	–4.865	–4.886	–4.907	–4.928	–4.948	–4.969	–4.989	–5.010	–5.030	–5.050	–5.069	–160
–150	–4.648	–4.670	–4.693	–4.715	–4.737	–4.758	–4.780	–4.801	–4.823	–4.844	–4.865	–150
–140	–4.419	–4.442	–4.466	–4.489	–4.512	–4.535	–4.558	–4.581	–4.603	–4.626	–4.648	–140
–130	–4.177	–4.202	–4.226	–4.251	–4.275	–4.299	–4.323	–4.347	–4.371	–4.395	–4.419	–130
–120	–3.923	–3.949	–3.974	–4.000	–4.026	–4.051	–4.077	–4.102	–4.127	–4.152	–4.177	–120
–110	–3.656	–3.684	–3.711	–3.737	–3.764	–3.791	–3.818	–3.844	–3.870	–3.897	–3.923	–110
–100	–3.378	–3.407	–3.435	–3.463	–3.491	–3.519	–3.547	–3.574	–3.602	–3.629	–3.656	–100
–90	–3.089	–3.118	–3.147	–3.177	–3.206	–3.235	–3.264	–3.293	–3.321	–3.350	–3.378	–90
–80	–2.788	–2.818	–2.849	–2.879	–2.909	–2.939	–2.970	–2.999	–3.029	–3.059	–3.089	–80
–70	–2.475	–2.507	–2.539	–2.570	–2.602	–2.633	–2.664	–2.695	–2.726	–2.757	–2.788	–70
–60	–2.152	–2.185	–2.218	–2.250	–2.283	–2.315	–2.348	–2.380	–2.412	–2.444	–2.475	–60
–50	–1.819	–1.853	–1.886	–1.920	–1.953	–1.987	–2.020	–2.053	–2.087	–2.120	–2.152	–50
–40	–1.475	–1.510	–1.544	–1.579	–1.614	–1.648	–1.682	–1.717	–1.751	–1.785	–1.819	–40
–30	–1.121	–1.157	–1.192	–1.228	–1.263	–1.299	–1.334	–1.370	–1.405	–1.440	–1.475	–30
–20	–0.757	–0.794	–0.830	–0.867	–0.903	–0.940	–0.976	–1.013	–1.049	–1.085	–1.121	–20
–10	–0.383	–0.421	–0.458	–0.496	–0.534	–0.571	–0.608	–0.646	–0.683	–0.720	–0.757	–10
–0	0.000	–0.039	–0.077	–0.116	–0.154	–0.193	–0.231	–0.269	–0.307	–0.345	–0.383	–0
0	0.000	0.039	0.078	0.117	0.156	0.195	0.234	0.273	0.312	0.351	0.391	0
10	0.391	0.430	0.470	0.510	0.549	0.589	0.629	0.669	0.709	0.749	0.789	10
20	0.789	0.830	0.870	0.911	0.951	0.992	1.032	1.073	1.114	1.155	1.196	20
30	1.196	1.237	1.279	1.320	1.361	1.403	1.444	1.486	1.528	1.569	1.611	30
40	1.611	1.653	1.695	1.738	1.780	1.822	1.865	1.907	1.950	1.992	2.035	40
50	2.035	2.078	2.121	2.164	2.207	2.250	2.294	2.337	2.380	2.424	2.467	50
60	2.467	2.511	2.555	2.599	2.643	2.687	2.731	2.775	2.819	2.864	2.908	60
70	2.908	2.953	2.997	3.042	3.087	3.131	3.176	3.221	3.266	3.312	3.357	70
80	3.357	3.402	3.447	3.493	3.538	3.584	3.630	3.676	3.721	3.767	3.813	80
90	3.813	3.859	3.906	3.952	3.998	4.044	4.091	4.137	4.184	4.231	4.277	90
DEG C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DEG C**

Table 17 (continued) — Temperature-EMF for type T thermocouples

Temperatures in degrees Celsius (IPTS-68) Reference junctions at 0°C

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
	THERMOELECTRIC VOLTAGE IN MILLIVOLTS											
100	4.277	4.324	4.371	4.418	4.465	4.512	4.559	4.607	4.654	4.701	4.749	100
110	4.749	4.796	4.844	4.891	4.939	4.987	5.035	5.083	5.131	5.179	5.227	110
120	5.227	5.275	5.324	5.372	5.420	5.469	5.517	5.566	5.615	5.663	5.712	120
130	5.712	5.761	5.810	5.859	5.908	5.957	6.007	6.056	6.105	6.155	6.204	130
140	6.204	6.254	6.303	6.353	6.403	6.452	6.502	6.552	6.602	6.652	6.702	140
150	6.702	6.753	6.803	6.853	6.903	6.954	7.004	7.055	7.106	7.156	7.207	150
160	7.207	7.258	7.309	7.360	7.411	7.462	7.513	7.564	7.615	7.666	7.718	160
170	7.718	7.769	7.821	7.872	7.924	7.975	8.027	8.079	8.131	8.183	8.235	170
180	8.235	8.287	8.339	8.391	8.443	8.495	8.548	8.600	8.652	8.705	8.757	180
190	8.757	8.810	8.863	8.915	8.968	9.021	9.074	9.127	9.180	9.233	9.286	190
200	9.286	9.339	9.392	9.446	9.499	9.553	9.606	9.659	9.713	9.767	9.820	200
210	9.820	9.874	9.928	9.982	10.036	10.090	10.144	10.198	10.252	10.306	10.360	210
220	10.360	10.414	10.469	10.523	10.578	10.632	10.687	10.741	10.796	10.851	10.905	220
230	10.905	10.960	11.015	11.070	11.125	11.180	11.235	11.290	11.345	11.401	11.456	230
240	11.456	11.511	11.566	11.622	11.677	11.733	11.788	11.844	11.900	11.956	12.011	240
250	12.011	12.067	12.123	12.179	12.235	12.291	12.347	12.403	12.459	12.515	12.572	250
260	12.572	12.628	12.684	12.741	12.797	12.854	12.910	12.967	13.024	13.080	13.137	260
270	13.137	13.194	13.251	13.307	13.364	13.421	13.478	13.535	13.592	13.650	13.707	270
280	13.707	13.764	13.821	13.879	13.936	13.993	14.051	14.108	14.166	14.223	14.281	280
290	14.281	14.339	14.396	14.454	14.512	14.570	14.628	14.686	14.744	14.802	14.860	290
300	14.860	14.918	14.976	15.034	15.092	15.151	15.209	15.267	15.326	15.384	15.443	300
310	15.443	15.501	15.560	15.619	15.677	15.736	15.795	15.853	15.912	15.971	16.030	310
320	16.030	16.089	16.148	16.207	16.266	16.325	16.384	16.444	16.503	16.562	16.621	320
330	16.621	16.681	16.740	16.800	16.859	16.919	16.978	17.038	17.097	17.157	17.217	330
340	17.217	17.277	17.336	17.396	17.456	17.516	17.576	17.636	17.696	17.756	17.816	340
350	17.816	17.877	17.937	17.997	18.057	18.118	18.178	18.238	18.299	18.359	18.420	350
360	18.420	18.480	18.541	18.602	18.662	18.723	18.784	18.845	18.905	18.966	19.027	360
370	19.027	19.088	19.149	19.210	19.271	19.332	19.393	19.455	19.516	19.577	19.638	370
380	19.638	19.699	19.761	19.822	19.883	19.945	20.006	20.068	20.129	20.191	20.252	380
390	20.252	20.314	20.376	20.437	20.499	20.560	20.622	20.684	20.746	20.807	20.869	390
400	20.869											400
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

Appendix A Bare thermocouple element fabrication

A.1 General

While completely fabricated thermocouples are available commercially, this Appendix is intended to assist those who desire to fabricate their own thermocouples.

A.2 Thermocouple wires

Carefully selected and tested pairs of thermocouple wires are available commercially in standard AWG diameters. When purchased as a pair simultaneously from a single supplier, the pair will conform to the specified calibration limits and be referred to as a matched pair.

1) Interchange of a common wire between two types of thermocouples (e.g., copper-nickel from Type J to T) or even between different matched pairs of the same type may yield a thermocouple that will not conform to the specified calibration limits.

2) See Appendix D for checking procedure and a reference on calibration.

A.3 Joining thermocouple wires

A.3.1 General

The dissimilar wires of a thermocouple must be joined at the temperature measuring junction by a joint of good electrical and thermal conductivity, without destroying the mechanical and metallurgical properties of the thermocouple wires at this joint.

1) For use below 500°C (1000°F) most base metal thermocouple wires may be silver soldered using borax as a flux.

2) Above 500°C (1000°F) experience has shown that properly welded thermocouple junctions provide long life and excellent thermal and electrical properties. Welded thermocouple junctions are used in practically all industrial applications today. Noble metal thermocouples should always be joined by welding. Common methods of welding thermocouples are gas, electric arc, resistance, tungsten-inert-gas and plasma-arc welding.

A.3.2 Preparation of wires

1) Often the matched wires must be straightened prior to joining to facilitate stringing of insulators in the final thermocouple assembly, but where possible, excessive bending of thermocouple wires should be avoided because cold working may alter the EMF output of thermocouple wire. Hammering, stretching and excessive twisting should be avoided for the same reason.

2) The thermocouple wires are cut to the length desired allowing for one or two attempts at welding and for any forming that must be done at the junction.

3) All thermocouple wire should be cleaned carefully with a suitable solvent such as Freon TF*, Methyl-Ethyl-Ketone, or Alcohol (such as Isopropyl) prior to welding.

4) Simple jigs and fixtures are usually used to shape the wires prior to welding, except for butt welded thermocouples which are often bent around a mandrel after welding. Care must be taken to avoid nicking or damaging the wire during the forming operation as damage to the wire or wire surface may shorten thermocouple life. The wires should be spaced to permit free insertion into insulators.

A.3.3 Gas or arc welding Types, E, J, K and T thermocouples

In preparation for welding, the wires may be twisted as shown in Figure A-1 or positioned in a "V" as shown in Figure A-4. The twisted construction adds strength and facilitates welding.

For twisted AWG sizes 8 and 14, one inch of each wire should be prepared by removing any oxide or other surface finish with abrasive paper or by very careful filing or grinding. For twisted AWG 20, 24, and 28, the prepared length need be only one-half inch. The prepared ends are either twisted together to yield one and one-half turns as shown in Figure A-1 or positioned in a "V" as shown in Figure A-4 and then welded.

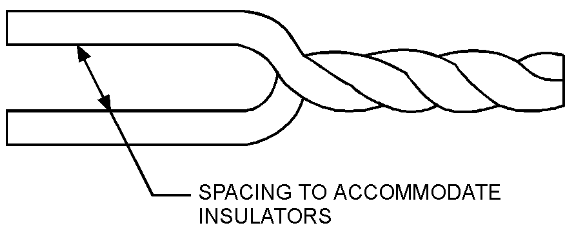

Figure A-1 — Method of twisting wires for gas and electric arc welding

A.3.4 Resistance welding Types J and K thermocouples

This method is recommended only for the 8 and 14 AWG wires. Approximately one-half inch of each wire should be sanded, in preparation for welding, with abrasive paper or by very careful filing or grinding.

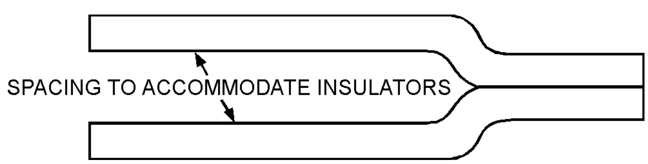

Figure A-2 — Method of forming metal wires for resistance welding

The sanded ends should be formed to produce longitudinal contact as shown in Figure A-2.

A.3.5 Butt resistance welding Types E, J, and K thermocouples

This method is recommended for 8 through 20 AWG wires and requires a good, commercially available, wire butt welder of suitable current capacity for the gage wire being welded. Approximately 0.5 inch of each wire should be sanded with abrasive paper in preparation for welding.

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*Trade name

The sanded ends of the straight wires are butted together in the spring loaded butt welder jaws and spring pressure applied to the jaws. The weld is performed and the flash is removed by grinding. The wires are then bent as shown in Figure A-3.

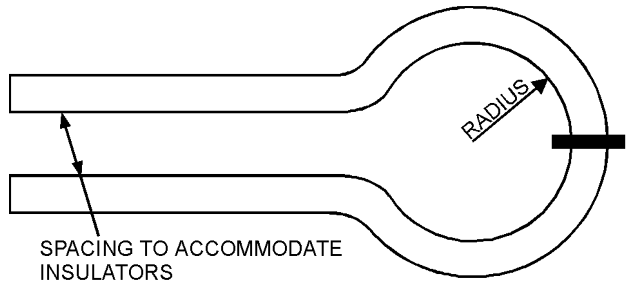

Figure A-3 — Formed butt-welded thermocouple

A.3.6 Resistance welding Types B, R, and S thermocouples

Extreme care should be taken to avoid cold working and contamination by oils, perspiration, dirt, etc. Sanding is not required.

The ends should be formed to produce a longitudinal contact of about one-eighth inch as shown in Figure A-2.

A.3.7 Arc welding Types B, R, and S thermocouples

Extreme care should be taken to avoid cold working and contamination by oils, perspiration, dirt, etc. Sanding is not required.

The ends of the wires are positioned as shown in Figure A-4.

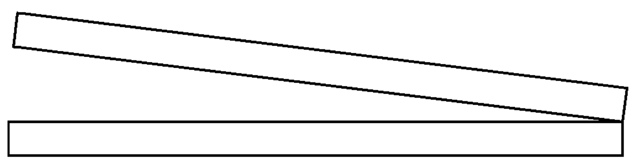

Figure A-4 — Method of forming metal wires for electric arc welding

A.3.8 Gas welding

The character of the gas flame is the primary consideration of gas welding. A neutral flame as shown in Figure A-5 is essential. The neutral flame is obtained by increasing the oxygen until the excess gas flame — shown dashed in Figure A-5 — just vanishes. Overshooting the vanishing point gives an oxidizing flame. AN OXIDIZING FLAME IS INJURIOUS AND SHOULD NEVER BE USED.

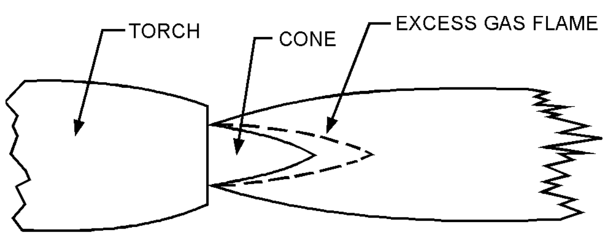

Figure A-5 — Neutral flame for gas welding

The smallest tip, that will readily heat the wires to fusion temperature, should be used. Continued heating at welding temperatures yields a poor weld.

Heat the ends of the twisted or "V" positioned wires to redness with the tip of the cone and plunge them into the flux. Reheat the wires to fusion temperature simultaneously, and rotate the weld to form a ball at the tip. Quench the welded junction in water to remove excess flux.

Attainment of the simultaneous fusion requires that the heating of the lower melting wire (see Table A-1) be delayed.

The junction should be examined with a low power magnifier for smoothness. A weld with a pitted surface must be rejected because it is burned (i.e., overheated to the point of incipient melting or intergranular oxidation). Repair of the weld is not feasible. An unsatisfactory weld must be cut off and the procedure repeated.

A.3.9 Electric arc welding

Welded junctions may also be produced by an arc between two soft carbon electrodes or between one carbon electrode and the thermocouple wires as the second electrode. Only 8 and 14 AWG thermocouples should be used as the second electrode. Finer wires require two carbon electrodes. Direct current (dc) or alternating current (ac) may be used, but direct current is preferred. With direct current and a single carbon electrode, the thermocouple is connected to the positive lead. The ends of the twisted or "V" positioned wires are moistened, dipped into flux, and clamped upright in a vise with copper jaws. (Avoid surface damage in clamping.)

The two leads from the variable electric current source are connected either to the two carbon electrodes or one to the carbon electrode and the other to the vise clamping the thermocouple.

The size of the pure, soft carbon electrodes should be proportional to the wire size.

An arc is struck between the carbon electrodes or carbon electrode and thermocouple by momentary shorting. For an 8 AWG thermocouple 30 to 45 volts is typical, and this value should be proportionately reduced for smaller sizes. With the single carbon electrode, a 1/16 inch arc gap minimizes oxidation and nitrogen absorption.

A brief welding cycle is best, since excessive current will result in burning. The bead should be small and solid. Bridges or gaps between the wires are weak and unsatisfactory. If an unsatisfactory weld results, it must be cut off and the procedure repeated.

A.3.10 Electric resistance welding

Heating and fusion of the wires are accomplished by resistance heating of the wires and by contact resistance at their junction. This method is recommended only by Types B, R, and S, and the 8 and 14 AWG sizes of Types J and K. The junction of Figure A-2 is placed between the electrodes of a resistance welder. A suitable pressure-current-time cycle must be established by trial-and-error on identical scrap wires or by experience. Visual and destructive examination are required to establish proper welding conditions. Excessive pressure will produce a good looking weld but only peripheral fusion. An unsatisfactory weld must be cut off and the procedure repeated.

A.3.11 TIG and plasma arc welding

The tungsten-inert gas (TIG) welding process and plasma arc welding process are rapidly gaining in importance for welding thermocouple junctions. These welding processes use an inert gas envelope to protect the weld from oxidation in lieu of a flux. Welding using the TIG or plasma arc processes is done following the same routine as welding with one carbon electrode, except a flux is not used. The plasma arc has distinct advantages such as: no tungsten inclusions in the weld, extremely high temperatures in the plasma arc, a more controllable arc, and a constant pilot arc which can actually be used for fine welding, as well as a guide light to position the torch prior to starting the main arc, to name but a few. These processes are especially recommended for welding junctions in sheathed thermocouple wire. Procedures outlined above may also be used on Types B, R, and S.

Table A-1 — Summary of methods for joining of bare wire thermocouples

Type of T/C*	Lower Melting	Silver Brazing	Welding			Resistance Welding	Plasma Arc or TIG	Butt Welding
			Flux**	Gas	Arc			
B	BN	N.R.†	None	A3.1.2	A.3.7 & A3.9	A3.6 &A3.9	A3.11	—
E	EN	A3.1.1	Fluorspar	A3.3 & A3.8	A3.3 & A3.9	N.R.	A3.11	A3.5
J	JN	A3.1.1	Borax	A3.3 & A3.8	A3.3 & A3.9	A3.4 & A3.10	A3.11	A3.5
K	KN	A3.1.1	Fluorspar	A3.3 & A3.8	A3.3 & A3.9	A3.4 & A3.10	A3.11	A3.5
R	RN	N.R.	None	A3.1.2	A3.7 & A3.9	A3.6 & A3.9	A3.11	—
S	SN	N.R.	None	A3.1.2	A3.7 & A3.9	A3.6 & A3.9	A3.11	—
T	TP	A3.1.1	Borax	A3.3 & A3.8	A3.3 & A3.9	N.R.	A3.11	N.R.

*See Table 1 of Standard for typical alloys
**Boric Acid also recommended for Types J, E, and K
†N.R. -Not recommended

NOTE: Numbers in body of table refer to paragraphs in Appendix A where the procedure for that type of joining is covered.

Appendix B Sheathed thermocouple element fabrication

B.1 General

Sheathed thermocouple elements may be fabricated from commercially available sheathed thermocouple wire described in Chapter 5 of ASTM Special Technical Publication 470B. Fabricating such thermocouples successfully requires a higher degree of skill, special equipment and techniques, and virtually clean room conditions compared to fabricating customary bare wire thermocouples. Although this appendix is intended to assist those who desire to fabricate their own sheathed thermocouple elements, only general fabrication procedures are outlined below. A study of the literature on sheathed thermocouples and Chapter 5 of ASTM Special Technical Publication 470B, plus refinement of the procedures outlined below by practical experience are pre-requisites to successful fabrication of sheathed thermocouple elements.

B.2 Special equipment

Although it is possible to remove the sheath by grinding and filing, special sheath stripping tools are commercially available and are highly recommended.

Welding is generally done using the Tungsten-Inert-Gas (TIG) process, and therefore a TIG welder is recommended. A plasma-arc welder is also excellent for this purpose.

It is often desirable to remove the insulant from around the thermocouple wires. Although this can be accomplished by tedious picking with a needle or other sharp instrument a miniature sandblaster is far superior.

A clean, dry and well lighted work area is essential to creating a finished element of high integrity.

Ovens capable of continuous operation at a minimum temperature of 200°F are suggested for storage of unsealed sheathed thermocouple wire and thermocouple elements during even short periods of delay where the compacted insulation might be exposed to air-borne moisture or other contaminants.

Special holding vises or fixtures are recommended for junctioning and capping sheathed thermocouple wire. The jaws may be made of commercial copper, and should be grooved to accept the various diameters of sheathed wire with which the fabricator plans to work.

B.3 General precautions

The crushed mineral oxide insulation in all sheathed thermocouple wire will rapidly absorb moisture. Thus the cable should be purchased with the ends closed by welding or suitably sealed in some other manner. Unsealed cable should be stored in an oven at 200°F or higher to reduce moisture pick-up.

All fixtures, vises and other tools brought into contact with the ceramic in the sheathed wire should be surgically clean to prevent contamination of the ceramic.

B.4 Measuring junction fabrication

Exposed Junction (Wires not encased within sheath end closure.) The sheathed wire is cut to the desired length allowing for reference junction and measuring junction sheath removal. The sheath is removed from both ends as required, and the wires are cleaned by sandblasting or other suitable means. Wires are positioned and lightly clamped in a fixture such as a special copper jaws vise so that approximately 1/32 in. of wires are exposed above the vise jaws. The wires must touch one another at the surface of the jaws. The junction is fused by an electrical arc using the TIG welder with the ground lead connected to the vise jaws. The finished junction should look like Figure B-1. Both ends of the thermocouple element must be sealed with a suitable sealer to prevent contamination of the insulation, or the thermocouple element can be stored in an oven at 200°F until it is used.

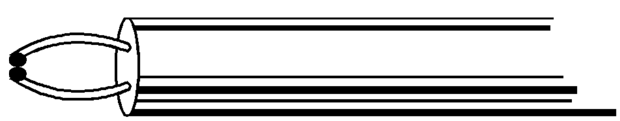

Figure B-1 — Typical exposed junction

Grounded Junction (Wires encased within sheath end closure.) The sheathed wire is cut to the desired length allowing for the reference end sheath removal.

B.4.1 On sheath diameters of 0.125 in. and smaller, the sheath and wires of the squared end can be simply welded over thus captivating both the sheath and the wires into the cap weld, creating a sound mechanical joint as well as electrical contact between the wires without diluting the cap weld metal with metal from the thermoelements. This weld is performed by positioning the squared end in a fixture such as copper jaws in a vise with closely fitting grooves for each size of sheathed wire. See Figure B-2.

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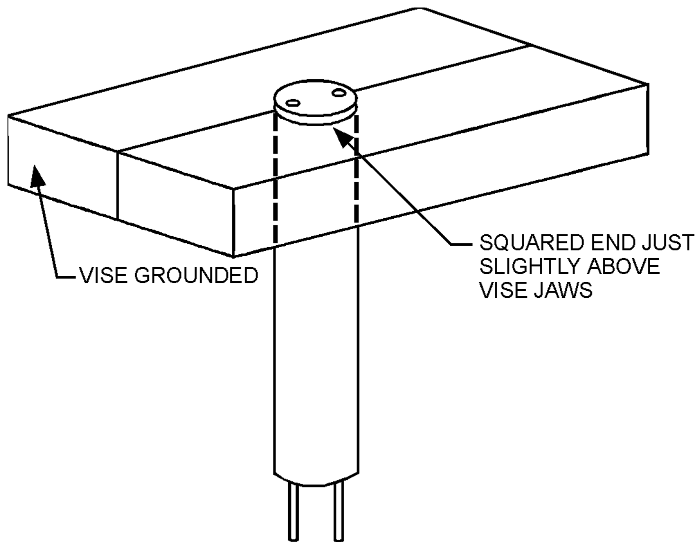

Figure B-2 — Fixturing for weldment

A TIG welder or plasma arc welder are best suited for welding, adding filler metal compatible with the sheath material as required.

B.4.a Sheath diameters larger than 0.125 in. require slightly different methods. After squaring the end, a portion of the insulation is removed to a depth equal to approximately the inside diameter of the sheath. The reference junction end must have the sheath removed and the wires exposed to which the ground clamp from the welder is attached. The unit is positioned in the vise jaws in the same fashion as for forming the cap weld. An arc is struck on the wires thereby fusing them into a neat ball. The end is then capped as on smaller sheathed elements bringing the weld metal down into intimate contact with the welded wires, but not re-melting them. The general configuration of a grounded junction is shown in Figure B-3.

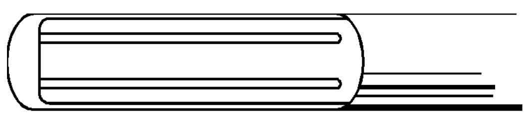

Figure B-3 — Cutaway view of grounded junction

B.4.3 Ungrounded Junction (Wires encased within but not touching sheath end closure.) The procedure for producing this form of junction is not too unlike that of the grounded junction in sheathed wire larger than 0.125 in. O.D. After preparing the ends by squaring and removing the sheath, the insulation is removed on the measuring junction end to a level which will allow the wires to be welded together to the proper depth from the squared end. Care must be taken not to create a weld ball as large as the sheath I.D. which will ground the wires to the sheath and defeat the purpose of this type of junction. After the wires are joined, an insulation powder equivalent to that within the sheath is packed tightly around the welded wires and out flush to the squared end of the sheath. Capping is then done as before. Figure B-4 is typical of an Ungrounded Junction

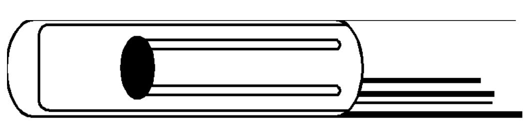

Figure B-4 — Cutaway view of ungrounded junction

B.4.4 The hygroscopic nature of most compacted insulations demands extreme care to avoid moisture pickup. It is very important to seal all ends where insulation is exposed as quickly and completely as possible.

Appendix C Thermocouples and thermocouple extension wires — selection, assembly, and installation

C.1 Scope and purpose

This section gives general information on the selection, assembly, and installation of commonly used thermocouples and associated thermocouple extension wires for specific applications.

C.2 Types and uses

There are seven thermocouple types now in general use. The material designations are shown in Table C-1. The positive element of each couple is listed first.

Each of these types has individual characteristics that are desirable for some applications and unsuitable for others. In addition to the usual insulated forms all couples are available as compacted ceramic insulated thermocouples (See Section 2.2.8.)

Type T may be used in a vacuum, inert, oxidizing or reducing atmosphere. It commonly is used for sub-zero temperatures and has an upper temperature limit of 370°C (700°F) for wires at least 0.064 in. (1.63 mm) in diameter, in conventional closed-end protecting tubes. Its copper positive element is preferred to the iron positive element of the Type J type for sub-zero use because of its superior corrosion resistance in moist atmospheres.

Type J may be used in a vacuum, inert, oxidizing, or reducing atmosphere. With elements of at least 0.128 in. (3.25 mm) in diameter, in conventional closed-end protecting tubes, it has an upper temperature limit of 760°C (1400°F). At high temperatures it should not be used in certain hydrogen containing atmospheres due to possible embrittling effects on the iron element. While this couple is occasionally used for sub-zero temperature measurements, the possible rusting or embrittlement of the iron under these conditions is at times undesirable.

Type E may be used in a vacuum, inert, oxidizing atmosphere and for temperatures up to 870°C (1600°F) for element wires at least 0.128 in. (3.25 mm) in diameter in closed-end protecting tubes. At sub-zero temperatures, the couple is not subject to corrosion. This thermocouple has the highest EMF output of any standard metal thermocouple.

Type K nominally is used to an upper temperature limit of 1260°C (2300°F) for wires at least 0.128 in. (3.25 mm) in diameter in conventional closed-end protecting tubes. It should be used either in inert or oxidizing atmospheres. It has a short life in atmospheres that are marginally oxidizing, alternately oxidizing and reducing, or reducing atmospheres, particularly in the temperature range of 820°C to 1010°C (1500°F to 1850°F). An oxidizing atmosphere inside the protecting tube may be obtained by providing adequate ventilating. The use of a sufficiently large protecting tube and an open head will be of material assistance. Type K thermocouples should not be used for accurate temperature measurements below 480°C (900°F) after prolonged exposure above 760°C (1400°F).

Table C-1 — Thermocouple types

Type	Thermocouple element	Thermocouple wire materials*
B	BP BN	Platinum - 30% rhodium Platinum - 6% rhodium
E	EP EN	Nickel Chromium Copper Nickel
J	JP JN	Iron Copper Nickel
K	KP KN	Nickel Chromium Nickel Aluminum Silicon
R	RP RN	Platinum - 13% rhodium Platinum
S	SP SN	Platinum -10% rhodium Platinum
T	TP TN	Copper Copper Nickel

*These thermocouple materials are defined by their EMF characteristics. Alloy compositions may vary from lot to lot.

Types R and S may be used for temperatures up to 1480°C (2700°F) and Type B to 1700°C (3100°F) for wires at least 0.020 in. (0.51 mm) in diameter in conventional closed-end protecting tubes. These thermocouples are easily contaminated and should always be used in a protecting tube. The protecting tube also should be non-metallic and silica free, since the thermocouple can be contaminated by metallic vapors, reduced oxides, or other impurities at high temperatures. These elements may be used in inert or oxidizing atmospheres and for short periods of time in a vacuum - longer periods of time in vacuum if, for example, gas tight ceramic tubes or metal sheaths are used. They should not be used in a reducing atmosphere. Type S thermocouples are frequently used for calibration or checking since this type is one of the primary standards.

C.3 Assembly

The fabrication of thermocouples requires special techniques as described in Appendix A. If the equipment and skill required to fabricate thermocouples properly are not available, the user should purchase fabricated thermocouples, since improper techniques can result in significant errors in temperature measurements.

Wire for making thermocouples preferably should be purchased in matched pairs in order to insure accuracy within standard limits of error of Section 3. However, positive and negative wires for types E, K, and T thermocouples, purchased at different times or from different suppliers, can be combined interchangeably. Wires to special limits of error given in Section 3 are obtained by selection and always should be purchased in matched pairs.

It is essential that the thermocouple have the same calibration as the instrument with which it is to be used.

Hard-fired ceramic insulators are used on most bare thermocouple elements. Insulators are available in single, double or multi-bore and a variety of shapes, sizes and lengths.

For Types B, R, and S thermocouples it is recommended that insulators be of aluminum oxide and be of one piece, full length construction, to provide maximum protection from contamination. The insulator should also be light in weight or the assembly designed to minimize mechanical stresses on the noble metal wire.

For base metal thermocouples, insulation of braided glass or other fabric is sometimes used. Such materials should not be used with noble metal elements, as they will contaminate the thermocouple. Thermocouples may be made from insulated thermocouple wire, provided the insulation is suitable for the exposure temperature and intended service and will not contaminate the thermocouple or environment.

Protecting tubes are used for most thermocouple installations to prevent contamination of the thermocouple and provide mechanical protection and support. The minimum diameter of the protecting tube must be such as to accommodate the thermocouple element. However, larger diameter tubes are often required for (a) strength, (b) to permit insertion of a checking thermocouple alongside the service thermocouple and (c) to provide an adequate diameter to length ratio to assist in maintaining an oxidizing atmosphere for Type K or E thermocouples. One-half, three-fourths, and one-inch pipe size tubes are commonly used.

The length of the protecting tube (and thermocouple element) should be such as to place the measuring junction of the thermocouple well into the medium, the temperature of which is to be measured. A minimum immersion length of 8 to 10 tube diameters is recommended in order to minimize conduction errors.

Protection tubes must be internally clean and free of sulphur-bearing compounds, oil, oxides, and sulphur-bearing compounds. A wide range of metal and ceramic protecting tubes is available. Depending upon the application, the protecting tube should have some or all of the following properties:

1) Mechanical strength to withstand pressure and resist sagging at high temperatures.
2) Temperature resistance to withstand the temperature being measured; thermal shock resistance so that sudden temperature changes will not damage the tube.
3) Corrosion resistance to avoid chemical action with the medium in which the tube is immersed.
4) Erosion resistance.
5) Low porosity at operating temperature. This is especially true of protecting tubes installed in furnaces since furnace gases are generally damaging to thermocouples.

Some of the common protection tube materials and the maximum operating temperatures are given in Table C-2.

Table C-2 — Protection tubes

Protecting tube material	Maximum operation temperature	
	Deg. C	Deg. F
Carbon Steel	540	1000
Wrought Iron	700	1300
Cast Iron	700	1300
304 Stainless Steel	870	1600
316 Stainless Steel	870	1600
446 Stainless Steel	980	1800
Nickel	980	1800
75 Nickel - 15 Chromium-Iron	1150	2100
Porcelain	1650	3000*
Silicon Carbide	1650	3000
Alumina-Silica	1650	3000*
Aluminum Oxide	1750	3200*

*Horizontal tubes should receive additional support above 1480°C (2700°F)

In addition to the conventional thermocouple construction described in this Appendix, sheathed, compacted, ceramic insulated thermocouple material is in common use. This material consists of one or more thermoelements encased in ceramic insulating material (usually magnesium oxide) which is firmly compacted within a metallic sheath. The nature of this construction is such as to require special fabricating techniques, and it is therefore recommended that the user purchase such thermocouples completely fabricated.

1) Sheathed, compacted thermocouple material can be obtained in (a) all calibration types, (b) a variety of sheath diameters ranging from 0.010 in. to 0.500 in. diameter and (c) a choice of sheath materials to withstand specific environments. Insulating materials, other than magnesium oxide, are also available.

2) The choice of sheath diameter will depend upon such factors as life expectancy, speed of response requirements and space limitations. Large diameter material will provide longer life but will have a slower response. For a more complete discussion of sheathed, compacted, ceramic insulated thermocouples, the user is referred to ASTM "Manual on the Use of Thermocouples in Temperature Measurement," STP 470B.

C.4 Installation considerations for thermocouples

C.4.1 In installing thermocouples it must be always borne in mind that the EMF produced depends upon the difference in temperature between the measuring and reference junctions. With a fixed or known reference junction, the thermocouple thermometer is capable only of indicating the temperature attained by its measuring junction. It is thus necessary in a particular process to insure that the measuring junction is at the same temperature within the accuracy desired as the medium to be measured. The errors discussed elsewhere in this standard are negligible compared with those that may result by not making the installation in such a manner that the measuring junction attains the temperature to be measured.

The measuring junction temperature actually obtained in an installation is a result of the net heat supplied to that junction by the conventional modes of heat transfer, i.e., conduction, convection and radiation. Where protection tubes or wells are necessary in an installation, the problem is only aggravated. Among the many factors which influence the measuring junction temperature of a particular installation are:

1) Temperature of the surroundings
2) Velocity and properties of the fluid
3) Emissivity of the exposed surface
4) Thermal conductivity of thermocouple and well materials
5) Ratio of heat-transfer areas

Under installation conditions where the surrounding (duct wall) temperatures are appreciably different from the fluid temperatures in the case of gases, heat exchange will take place by the mechanism of radiation by the thermocouple and its surroundings. In addition, heat will flow from or to the thermocouple by the mechanism of conduction, and heat will be transferred by convection. Depending upon whether the surrounding temperatures are higher or lower than the gas temperature, the thermocouple will indicate higher or lower temperature. Where great differences in temperature exist between the gas and the surroundings, publications on heat transfer should be consulted treating the thermocouple thermometer as a "thin-rod" type of problem.

The thermocouple thermometer should be located in a position where the mass velocity is as high as practicable to assure good heat transfer by convection; however, if the velocity is in excess of 300 ft./sec. then a specially designed stagnation-type probe should be used. When a thermocouple must be installed in a location where the velocity is very low, then it may be necessary to induce a flow of gases past the junction. Several aspirating types of pyrometers are available for this purpose.

C.4.2 A thermocouple connection head is recommended to provide positive connections between the thermocouple and the extension wire. The head also permits easy replacement of the thermocouple.

C.4.3 The protecting tube should extend beyond the outer surface of the vessel furnace or processing equipment so that the temperature of the connection head approximates the ambient atmospheric temperature. This is especially true for Types B, R, and S thermocouples using compensating extension wires. The connection head temperature should never exceed the temperature limits given in Section 3 for thermocouple extension wires.

C.4.4 After all the steps outlined above have been carried out, the actual installation of a thermocouple still requires some care. Both the thermocouple and the extension wire should be cleaned before fastening in the terminal block to assure good electrical contacts. Color-coded insulation identifies the positive and negative elements of the extension wire. It is necessary to have the thermocouple wire tagged or otherwise identified as to polarity. The following information can be used to determine polarity in the field.

C.4.4.1 For extension wire having insulation color-coded in accordance with Section 1, *the negative wire insulation is always colored red*.

C.4.4.2 For Type E, the negative wire is silver in appearance. It has a lower resistance in ohms/foot than the positive element for the same size wire.

C.4.4.3 For Type J, the positive element is frequently rusty and is magnetic. It has a lower resistance in ohms/foot for the same size wire.

C.4.4.4 For Type K, the negative element is slightly magnetic. It has a lower resistance in ohms/foot for the same size wire.

C.4.4.5 For Type R and S, the negative wire is softer than the positive wire. The negative wire also has a lower resistance in ohms/foot for the same size wire.

C.4.4.6 For Type T, the positive wire is copper-colored and the negative wire is silver in appearance. The positive wire has lower resistance in ohms/foot for the same size wire.

C.4.5 Bottoming of the thermocouple in the protecting tube is often practiced to improve the response to temperature change. Bottoming consists of having the thermocouple junction pressed tightly against the end or "bottom" of the protecting tube. However, bottoming may ground the thermocouple which, with some types of installations causes difficulties.

C.4.6 It must be borne in mind that zero error is unattainable. In addition to the instrument error, the thermocouple and the extension wire will introduce errors. In Section 3 are tabulated the initial tolerances that can be expected in new materials. The installed components may deteriorate with use, and methods of checking the installation are given in Appendix D.

C.5 Installation of extension wires

C.5.1 Types of extension wires for use with various types of thermocouples are listed in Table C-3.

Table C-3 — Types of extension wire

Thermocouple type	Extension wire	Extension wire elements*
B	BX	BPX Copper BNX Copper
E	EX	EPX Nickel Chromium ENX Copper Nickel
J	JX	JPX Iron JNX Copper Nickel
K	KX	KPX Nickel Chromium KNX Nickel Aluminum
R or S	SX	SPX Copper SNX Copper Nickel Alloy
T	TX	TPX Copper TNX Copper Nickel

*These thermocouple materials are defined by their EMF characteristics. Alloy compositions may vary from lot to lot.

C.5.2 Potentiometer type instruments are not critical as to extension wire resistance. However, single wires and pairs smaller than 16-gage are not recommended for use in conduit, as they do not have sufficient strength for pulling. Twenty-gage and smaller wire may be used when assembled in suitable reinforced bundles to provide pulling strength. Where extension wire smaller than 16-gage is required, insulated thermocouple wire, instead of extension wire, may be used. The total resistance of the extension wire is important when used with galvanometer millivoltmeter-type instruments. Some millivoltmeters require a definite resistance in the extension wire.

Many of the more recent millivoltmeters are made with a high internal resistance. The extension wire used with these instruments does not have to be calibrated but the total resistance should be kept to approximately the value given on the instrument scale. Therefore, it is usually necessary to use a large size wire. Sizes 14- and 16-gage are recommended.

The resistance of electronic instruments is often high enough to place no restraint on the resistance of the extension wire.

Due to the fast response of such instruments, fluctuations due to noise may require noise suppression techniques.

C.5.3 The insulation used on extension wires may be divided into four general classifications: waterproof, moisture resistant, heat resistant, and radiation resistant. Materials used for insulating extension wire are selected to perform a variety of functions. These include: physical protection, bonding, mechanical separation, and electrical insulation.

In a permanently dry location these functions can be performed by non-conducting substances such as cotton, glass, asbestos fibers, paper tapes, and ceramic beads. Where moisture may be present, more or less impervious barriers are required. These may be enamel coatings, asphalt or wax impregnations, plastics, rubber or lead sheaths. Where heat resistance is necessary, glass, asbestos fibers, and ceramics may be used. Where the extension wire may be exposed to varying degrees of heat and moisture, a combination of two or more of these materials may give a satisfactory insulation.

C.5.4 Thermocouple extension wire should always be installed in the best manner to protect it from excessive heat, moisture, and mechanical damage. Wherever practicable it should be installed in conduit so that it is not subjected to excessive flexing or bending, which might change the thermoelectric characteristics.

The layout and arrangement of the conduits for a thermocouple system should be given considerable thought. Long radius bends should be used instead of elbows where possible; cold working of thermocouple elements can introduce inhomogeneity, and pulling of the extension wire through a number of elbows could work the wires unnecessarily .

While it is generally desirable to keep the length of extension wire as short as possible, it is often possible to have one conduit serve a number of thermocouples. The extent of conduit fill is not as significant with thermocouples as with power wiring because the lower current causes lower heating. (Conduit fill is the ratio between the cross-sectional area of all of the wires and the area of the conduit.)

For minimum error the extension wire should be run from the thermocouple connection head to the instrument terminal or reference junction in one continuous length; junction boxes may introduce errors and can be avoided by design of the conduit system with the proper pull points. When splices are unavoidable, they should be made by compressing the two wires to be joined with a mechanical device to obtain intimate contact. No other electrical wires should ever be run in the same conduit with extension wires.

When installing extension wire underground, always use waterproof insulation. Running extension wires parallel to or in close proximity to power lines should be avoided. When any connections are made, polarity must be strictly observed.

Appendix D Thermocouples-checking procedures

D.1 General

New thermocouples, thermocouple materials, and thermocouple extension wire are controlled by the supplier to fit a published temperature-EMF table or curve within stated tolerance limits. Thermocouple extension wire normally retains its original characteristics when used within recommended temperature limits, but thermocouples, which are exposed to high temperatures in various atmospheres, may change characteristics. To avoid the continued use of thermocouples with excessive deviations from the original characteristic due to such exposure or contamination, it is good practice to check the thermocouples at regular intervals.

New material, not previously exposed to temperature gradients, can be checked by techniques described in ASTM E-220-72.

D.2 Scope and purpose

Recommendations and suggestions are given below for simple and ordinarily adequate procedures for checking installed thermocouples. These are not intended to be completely self-sufficient, however, and usually it will be advantageous to consult more detailed treatments as well.

"Temperature Measurement," Part 3 of the Performance Test Codes Supplement on Instruments and Apparatus, PTC 19.3, published by the American Society of Mechanical Engineers, gives thorough coverage to the use and calibration of thermocouples. Calibrating procedures for new thermocouple materials are given in NBS Special Publication 300, Volume II, "Precision Measurement and Calibration-Temperature." This describes various testing methods and the precautions which must be observed in order to attain various degrees of accuracy. In particular, it describes in detail the methods developed and used at the National Bureau of Standards. Further information is available in E-220-72, "Calibration of Thermocouples by Comparison Techniques," published by the American Society for Testing and Materials.

D.3 Procedure

D.3.1 The checking of installed thermocouples is complicated by the thermoelectric non-uniformity resulting from contamination or deterioration of the elements. The unheated terminals of the used thermocouple will normally be like new — the actual junction, contaminated or deteriorated, and the intermediate material affected to various degrees.

The output of a contaminated or deteriorated thermocouple will not be determined solely by the temperature of the heated junction, as with a new homogeneous thermocouple, but also by the temperature gradient between the measuring and reference ends and the pattern of contamination and deterioration in the temperature gradient zone. FOR THIS REASON A USED THERMOCOUPLE SHOULD NOT BE REMOVED FROM ITS INSTALLED LOCATION AND PLACED IN A CALIBRATING FURNACE FOR CHECKING. IT IS HIGHLY IMPROBABLE THAT THE TEMPERATURE GRADIENTS IN THE TWO INSTALLATIONS WILL BE THE SAME.

A used thermocouple must be checked in its normal installed location. The purpose of checking an installed thermocouple is not to determine its temperature-EMF characteristics, but to determine the temperature error in actual service. This can most readily be done by temporarily installing a new or checking thermocouple along side the service thermocouple, or in its place, and comparing the readings. If the installed thermocouple is used to measure a wide range of temperatures, it should be checked at more than one temperature within the range of its use. Testing of a thermocouple at a single temperature yields some information, but it is not safe to assume that the changes in the EMF of the couple are proportional to the temperature or to the EMF.

D.3.2 Where the protecting tube is large enough, a checking thermocouple may be inserted beside the service thermocouple. It is recommended that a separate checking instrument be used with the checking thermocouple to permit checking of the service instrument, as well as of the service thermocouple.

Where the protecting tube is not large enough to permit the insertion of an additional thermocouple, it is necessary to remove the service thermocouple and to replace it with a checking thermocouple. When this method is used, it is essential that stable temperature conditions be maintained. In general, the higher temperature or more contaminating the atmosphere, the more frequently checks should be made.

D.3.3 Large temperature gradients can exist in commonly used furnaces and other devices, and points physically close together may be at surprisingly different temperatures. The procedure of checking a thermocouple installation by means of a checking thermocouple inserted through a furnace door or otherwise installed in a different part of the apparatus from the service thermocouple is not recommended, since the thermocouple reading may fail to agree and yet both may be correct.

D.3.4 Checking thermocouples or secondary standards should be homogeneous and uncontaminated. Any new thermocouple may be used, but it should be checked against a primary standard and tagged with its deviation from the standard curve. If a user does not have the equipment and technique for doing this, calibrated and tagged thermocouples are available. The National Bureau of Standards or other standardizing laboratories will furnish a report on the temperature-EMF characteristics of a submitted thermocouple.

D.3.5 The accuracy of a checking thermocouple or secondary standard will become questionable after use. Noble metal thermocouples may normally be relied upon for a considerable period of use, provided that the checking temperatures have not been avoided. Base metal thermocouples used for checking purposes should be checked frequently.

NOTE: Base metal couples should not be used for checking purposes below 480°C (900°F), if they are exposed between checks at temperatures above 760°C (1400°F).

Bibliography

ASTM Standard E220, "Standard Method for Calibration of Thermocouples by Comparison Techniques," American Society for Testing and Materials.

ASTM Special Technical Publication STP-470B, "Manual on the Use of Thermocouples in Temperature Measurement," American Society for Testing and Materials.

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See also standards of ASTM Committee E-20 on Temperature Measurement.

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ISBN: 0-87664-708-5