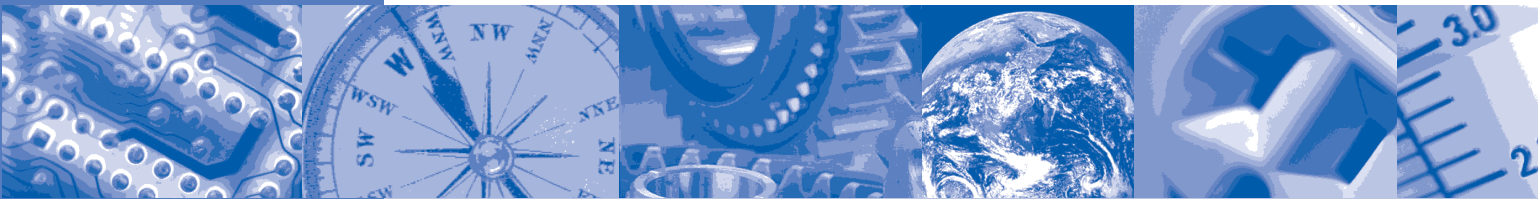


ISA-MC96.1-1982



Temperature Measurement Thermocouples



Approved 12 August 1982



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ISA-MC96.1 — Temperature Measurement Thermocouples

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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.



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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

Type*	Thermoelements	
	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

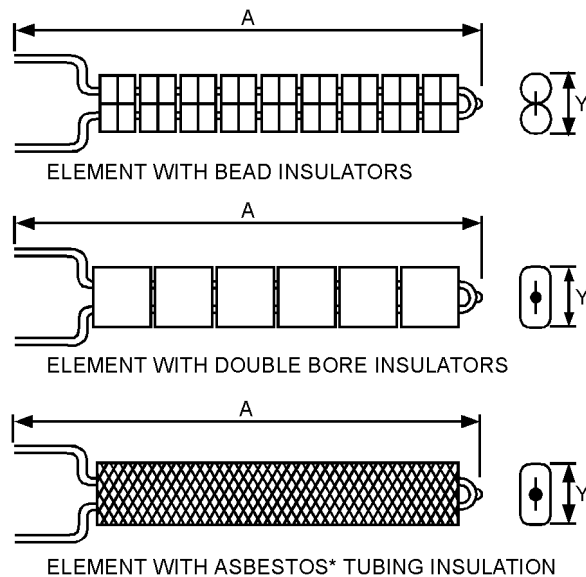
The tolerance of a thermocouple or extension wire is the maximum allowable deviation in degrees from the standard EMF-temperature values for the type of thermocouple in question when the reference junction temperature is at the ice point and the measuring junction is at the temperature to be measured.

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.



*Asbestos is being replaced with safer high-temperature materials.

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.)

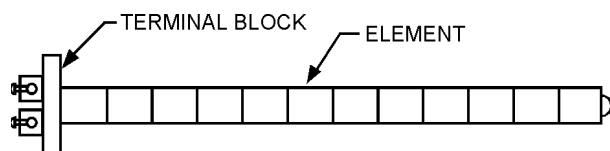


Figure 2 — Thermocouple element with terminal block

- 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.)

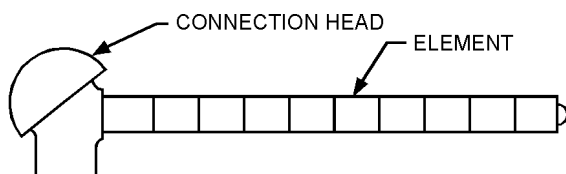


Figure 3 — Thermocouple element with connection head

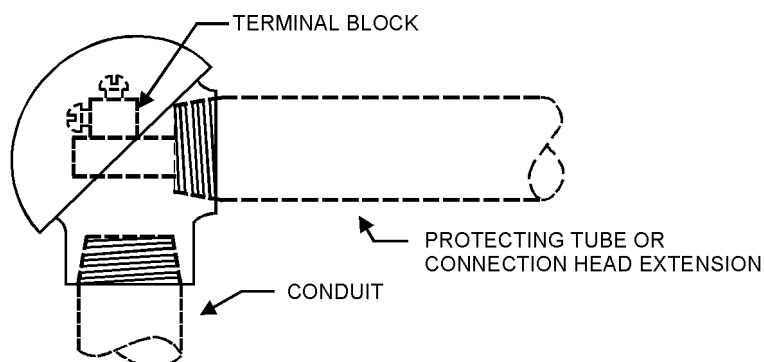


Figure 4 — Connection head

- 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.)

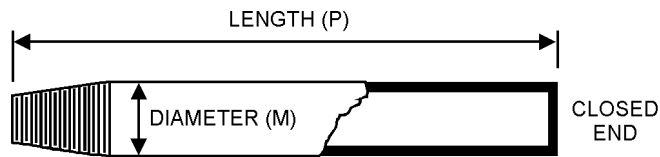


Figure 5 — Protecting tube

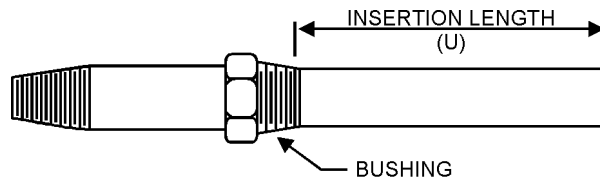


Figure 6 — Protecting tube with mounting bushing

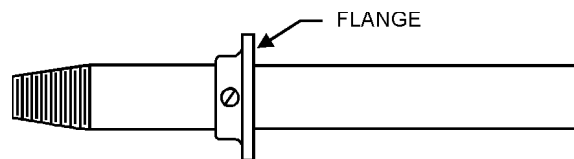


Figure 7 — Protecting tube with mounting flange

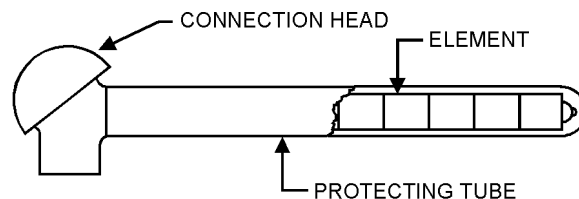


Figure 8 — Thermocouple element with protecting tube and connection head

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.)

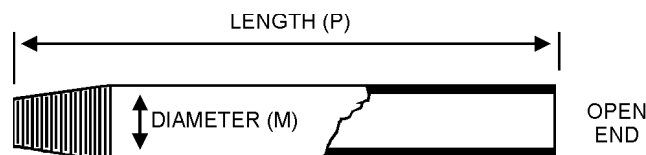


Figure 9 — Open end protecting tube

- 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 Figure 10.)

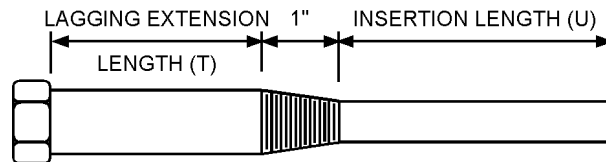


Figure 10 — Well

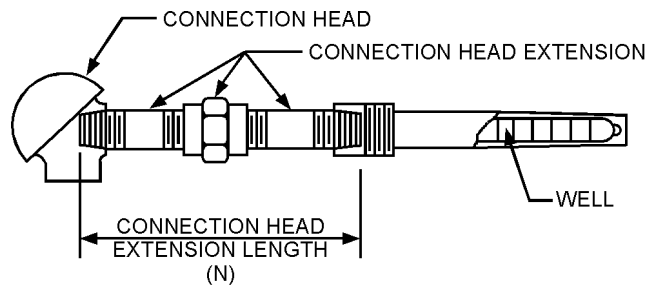


Figure 11 — Thermocouple assembly with thermowell

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.)

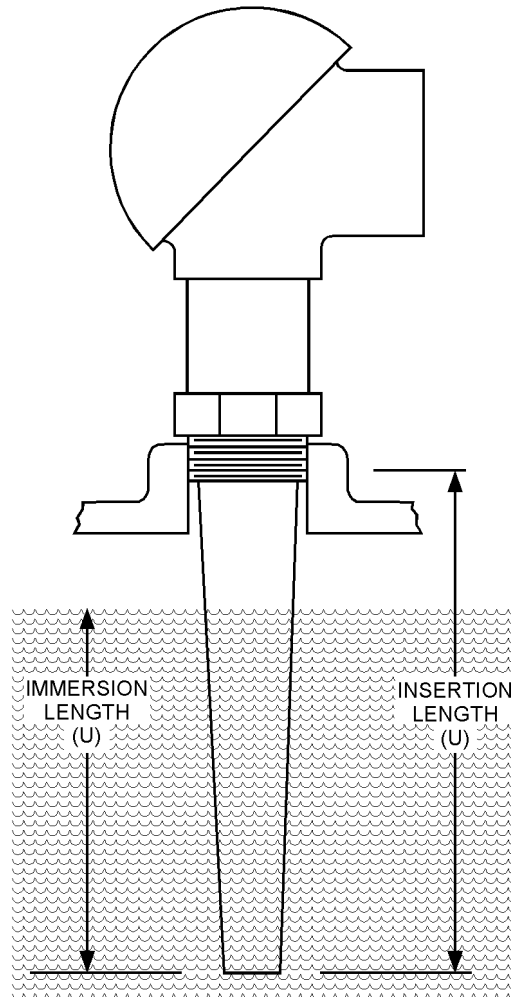


Figure 12 — Immersion and insertion lengths for thermocouple assembly with thermowell

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

	<u>Symbols</u>
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 $\pm 3/4$ percent. If the temperature being measured is 538°C, the tolerance is $\pm 3/4$ percent of 538, or $\pm 4.0^\circ\text{C}$. 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			
Thermocouple Type	Temperature Range, °C	TOLERANCES	
		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			
Extension Wire Type	Temperature Range, °C	Tolerances	
		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