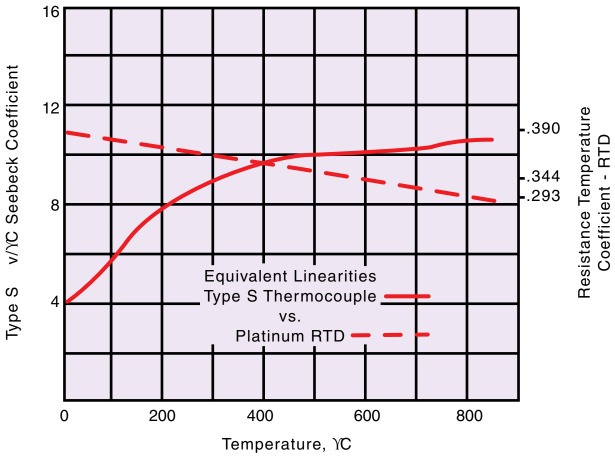


Figure 46

Practical Precautions

The same practical precautions that apply to thermocouples also apply to RTD's, *i.e.*, use shields and twisted-pair wire, use proper sheathing, avoid stress and steep gradients, use large extension wire, keep good documentation and use a guarded integrating dvm. In addition, the following precautions should be observed.

Construction - Due to its construction, the RTD is somewhat more fragile than the thermocouple, and precautions must be taken to protect it.

Self-Heating - Unlike the thermocouple, the RTD is not self-powered. A current must be passed through the device to provide a voltage that can be measured. The current causes Joule (I^2R) heating within the RTD, changing its temperature. This *self-heating* appears as a measurement error. Consequently, attention must be paid to the magnitude of the measurement current supplied by the ohmmeter. A typical value for self-heating error is ½°C per milliwatt in free air. Obviously, an RTD immersed in a thermally conductive medium will distribute its Joule heat to the medium, and the error due to self-heating will be smaller. The same RTD that rises 1˚C per milliwatt in free air will rise only 1⁄10°C per milliwatt in air which is flowing at the rate of one meter per second.[6]

To reduce self-heating errors, use the minimum ohms measurement current that will still give the resolution you require, and use the largest RTD you can that will still give good response time. Obviously, there are compromises to be considered.

Thermal Shunting - Thermal shunting is the act of altering the measurement temperature by inserting a measurement transducer. Thermal shunting is more a problem with RTD's than with thermocouples, as the physical bulk of an RTD is greater than that of a thermocouple.

Small RTD	Large RTD
Fast Response Time Low Thermal Shunting High Self-Heating Error	Slow Response Time Poor Thermal Shunting Low Self-Heating Error

Thermal EMF - The platinum-to-copper connection that is made when the RTD is measured can cause a thermal offset voltage. The offset-compensated ohms technique can be used to eliminate this effect.

THE THERMISTOR

Like the RTD, the thermistor is also a temperature sensitive resistor. While the thermocouple is the most versatile temperature transducer and the PRTD is the most stable, the word that best describes the thermistor is *sensitive*. Of the three major categories of sensors, the thermistor exhibits by far the largest parameter change with temperature.

Thermistors are generally composed of semiconductor materials. Although positive temperature coefficient units are available, most thermistors have a negative temperature coefficient (TC); that is, their resistance decreases with increasing temperature. The negative T.C. can be as large as several percent per degree Celsius, allowing the thermistor circuit to detect minute changes in temperature which could not be observed with an RTD or thermocouple circuit.

The price we pay for this increased sensitivity is loss of linearity. The thermistor is an extremely non-linear device which is highly dependent upon process parameters. Consequently, manufacturers have not standardized thermistor curves to the extent that RTD and thermocouple curves have been standardized.

An individual thermistor curve can be very closely approximated through use of the Steinhart-Hart equation:[18]

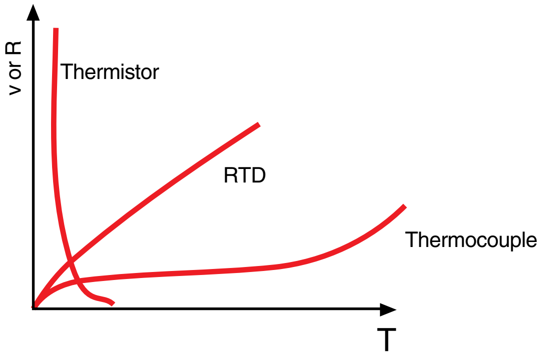


Figure 47

$$\frac{1}{T} = A + B\ln R + C(\ln R)^3$$

where:

T = Degrees Kelvin
R = Resistance of the thermistor
A,B,C = Curve-fitting constants

[6] *Refer to Bibliography 6.*
[18] *Refer to Bibliography 18.*

A, B, and C are found by selecting three data points on the published data curve and solving the three simultaneous equations. When the data points are chosen to span no more than 100˚C within the nominal center of the thermistor's temperature range, this equation approaches a rather remarkable ±.02°C curve fit.

Somewhat faster computer execution time is achieved through a simpler equation:

$$T = \frac{B}{\ln R - A} - C$$

where A, B, and C are again found by selecting three (R,T) data points and solving the three resultant simultaneous equations. This equation must be applied over a narrower temperature range in order to approach the accuracy of the Steinhart-Hart equation.

Linear Thermistors

A great deal of effort has gone into the development of thermistors which approach a linear characteristic. These are typically 2- or 4-leaded devices requiring external matching resistors to linearize the characteristic curve. The modern data acquisition system with its computing controller has made this kind of hardware linearization unnecessary.

Measurement

The high resistivity of the thermistor affords it a distinct measurement advantage. The four-wire resistance measurement is not required as it is with RTD's. For example, a common thermistor value is 5000 ohms at 25’C. With a typical T.C. of 4%/˚C, a measurement lead resistance of 100 produces only a .05°C error. This error is a factor of 500 times less than the equivalent RTD error.

Disadvantages - Because they are semiconductors, thermistors are more susceptible to permanent decalibration at high temperatures than are RTD's or thermocouples. The use of thermistors is generally limited to a few hundred degrees Celsius and manufacturers warn that extended exposures even well below maximum operating limits will cause the thermistor to drift out of its specified tolerance.

Thermistors can be made very small which means they will respond quickly to temperature changes. It also means that their small thermal mass makes them especially susceptible to self-heating errors.

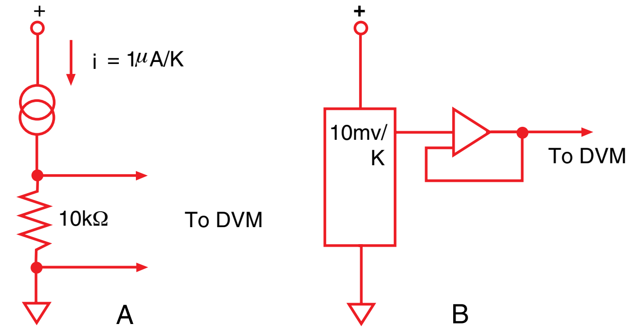
Thermistors are a good deal more fragile than RTD's or thermocouples and they must be carefully mounted to avoid crushing or bond separation.

MONOLITHIC LINEAR TEMPERATURE SENSOR

A recent innovation in thermometry is the integrated circuit temperature transducer. It is available in both voltage and current-output configurations. Both supply an output that is linearly proportional to absolute temperature. Typical values are 1 μA/K and 10 mV/K.

Except for the fact that they offer a very linear output with temperature, these devices share all the disadvantages of thermistor devices and thus have a limited temperature range. The same problems of self-heating and fragility are evident, and they require an external power source.

These devices provide a convenient way to produce an analog voltage proportional to temperature. Such a need arises in a hardware thermocouple reference junction compensation circuit (see Figure 15).



A
CURRENT SENSOR

B
VOLTAGE SENSOR

Figure 48

APPENDIX A

The Empirical Laws of Thermocouples[2]

The following examples illustrate the empirically derived "laws" of thermocouples which are useful in understanding and diagnosing thermocouple circuits.

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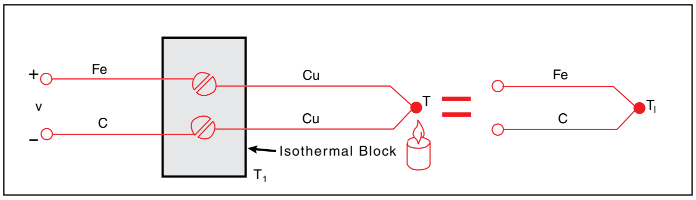
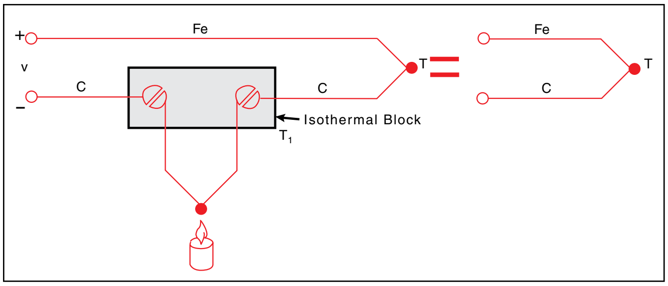
[2] Refer to Bibliography 2.



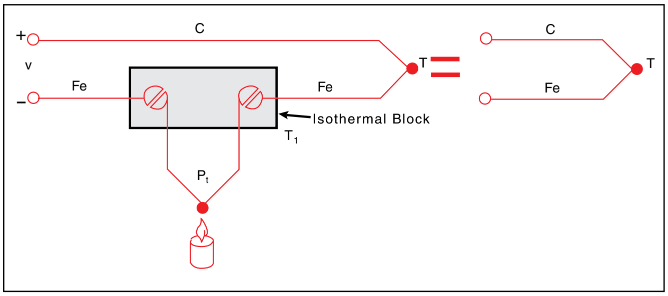
THE LAW OF INTERMEDIATE METALS

Inserting the copper lead between the iron and constantan leads will not change the output voltage V, regardless of the temperature of the copper lead. The voltage V is that of an Fe-C thermocouple at temperature T_1.



THE LAW OF INTERIOR TEMPERATURES

The output voltage V will be that of an Fe-C couple at Temperature T, regardless of the external heat source applied to either measurement lead.



THE LAW OF INSERTED METALS

The voltage V will be that of an Fe-C thermocouple at temperature T, provided both ends of the platinum wire are at the same temperature. The two thermocouples created by the platinum wire (FePt and Pt -Fe) act in opposition.

All of the above examples assume the measurement wires are homogeneous; that is, free of defects and impurities.

APPENDIX B

Thermocouple Characteristics

Over the years, specific pairs of thermocouple alloys have been developed to solve unique measurement problems. Idiosyncrasies of the more common thermocouples are discussed here.

We will use the term *standard wire error* to refer to the common commercial specifications published in the *Annual Book of ASTM Standards*. It represents the allowable deviation between the actual thermocouple output voltage and the voltage predicted by the tables in NBS Monograph 125.

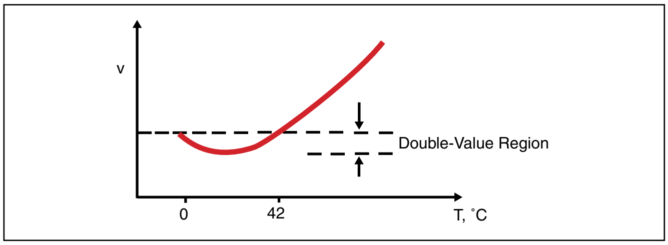
Noble Metal Thermocouples - The noble metal thermocouples, types B, R, and S, are all platinum or platinum-rhodium thermocouples and hence share many of the same characteristics.

Diffusion - Metallic vapor diffusion at high temperatures can readily change platinum wire calibration; therefore, platinum wires should only be used inside a *non*-metallic sheath such as high-purity alumina. The one exception to this rule is a sheath made of platinum, but this option is prohibitively expensive.

Stability - The platinum-based couples are by far the most stable of all the common thermocouples. Type S is so stable that it is specified as the standard for temperature calibration between the antimony point (630.74°C) and the gold point (1064.43˚C).

Type B - The B couple is the only common thermocouple that exhibits a double-valued ambiguity.

Due to the double-valued curve and the extremely low Seebeck coefficient at low temperatures, Type B is virtually useless below 50°C. Since the output is nearly zero from 0°C to 42°C, Type B has the unique advantage that the *reference* junction temperature is almost immaterial, as long as it is between 0˚ and 40˚C. Of course, the *measuring* junction temperature is typically very high.



Base Metal Thermocouples

Unlike the noble metal thermocouples, the base metal couples have no specified chemical composition. Any combination of metals can be used which results in a voltage vs. temperature curve fit that is within the standard wire errors. This leads to some rather interesting metal combinations. *Constantan*, for example, is not a specific metal alloy at all, but a generic name for a whole series of copper-nickel alloys. Incredibly, the *Constantan* used in a type T (copper-Constantan) thermocouple is not the same as the *Constantan* used in the type J (iron -Constantan) couple.[3]

---

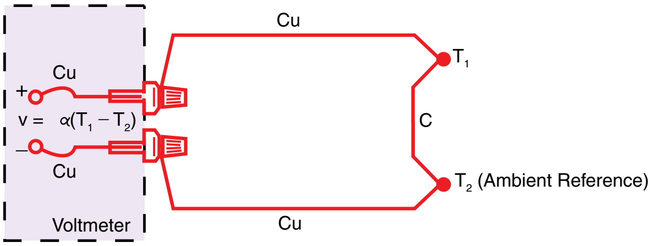
[3] *Refer to Bibliography 3*

Type E - Although Type E standard wire errors are not specified below 0°C, the type E thermocouple is ideally suited for low temperature measurements because of its high Seebeck coefficient (58 μV/°C), low thermal conductivity and corrosion resistance.

The Seebeck coefficient for Type E is greater than all other standard couples, which makes it useful for detecting small temperature changes.

Type J - Iron, the positive element in a J couple, is an inexpensive metal rarely manufactured in pure form. J thermocouples are subject to poor conformance characteristics because of impurities in the iron. Even so, the J couple is popular because of its high Seebeck coefficient and low price.

The J couple should never be used above 760°C due to an abrupt magnetic transformation that can cause decalibration even after the instrument cools.



TYPE T

Type T - This is the only couple with published standard wire errors for the temperature region below 0°C; however, type E is actually more suitable at very low temperatures because of its higher Seebeck coefficient and lower thermal conductivity.

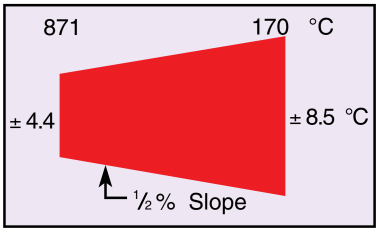
Type T has the unique distinction of having one copper lead. This can be an advantage in a specialized monitoring situation where a temperature difference is all that is desired.

The advantage is that the copper thermocouple leads are the same metal as the dvm terminals, making lead compensation unnecessary.

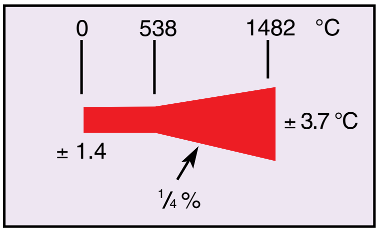
Types K & Nicrosil-Nisil - The Nicrosil-Nisil thermocouple, type N, is similar to type K, but it has been designed to minimize some of the instabilities in the conventional Chromel-Alumel combination. Changes in the alloy content have improved the order/disorder transformations occurring at 500˚C, and a higher silicon content in the positive element improves the oxidation resistance at elevated temperatures. A full description with characteristic curves is published in NBS Monograph 161.[14]

Tungsten - Tungsten-rhenium thermocouples are normally used at high temperature in reducing or vacuum environments, but never in an oxidizing atmosphere because of the high reaction rates. Pure tungsten becomes very brittle when heated above its recrystallization temperature (about 1200°C). To make the wire easier to handle, rhenium alloys are used in both thermocouple legs. Types G (tungsten vs. tungsten 26% rhenium), C (tungsten 5% rhenium vs. tungsten 26% rhenium) and D (tungsten 3% rhenium vs. tungsten 25% rhenium) thermocouples are available in bare wire forms as well as complete probe assemblies. All materials conform to published Limits of Error.

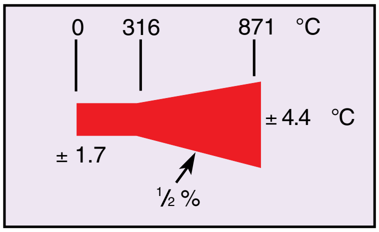
ASTM STANDARD WIRE ERRORS[3]



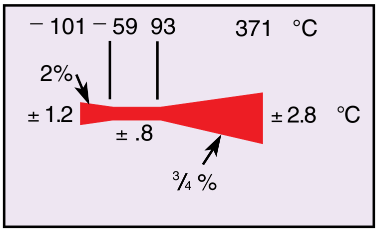
TYPE B 24 AWG



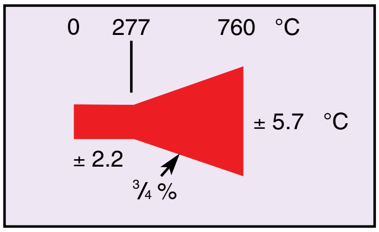
TYPE R,S 24 AWG



TYPE E 8 AWG

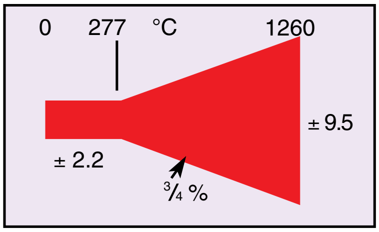


TYPE T 14 AWG



TYPE J 8 AWG

At high temperatures, small thermocouple wire is affected by diffusion, impurities, and inhomogeneity more so than large wire. The standard wire errors reflect this relationship.



TYPE K 8 AWG

Note that each NBS wire error specification carries with it a wire size. The noble metal thermocouples (B, R, and S) are specified with small (24 ga.) wire for obvious cost reasons.

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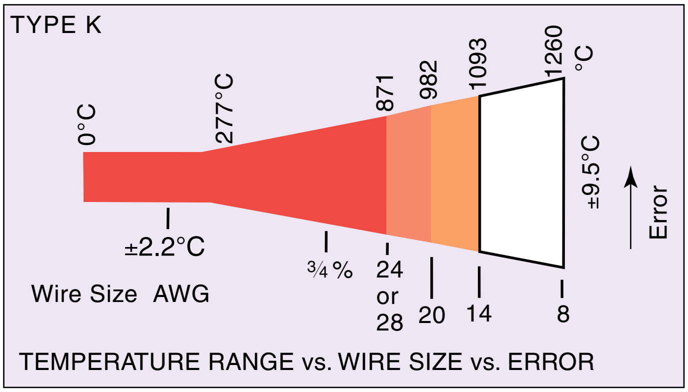
[3] Refer to Bibliography 3
[14] Refer to Bibliography 14

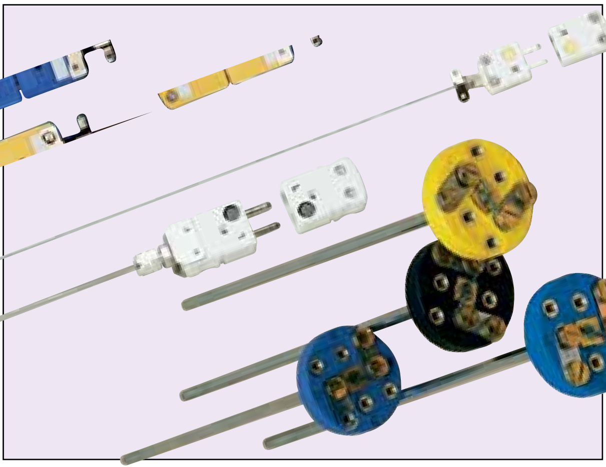


TEMPERATURE RANGE vs. WIRE SIZE vs. ERROR

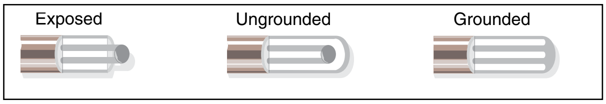
AWG	DIA, MILS	DIA, mm
8	128	3.3
10	102	2.6
12	81	2.1
14	64	1.6
16	51	1.3
18	40	1
20	32	0.8
22	25	0.6
24	20	0.5
26	16	0.4
28	13	0.3

TYPE	METAL +	METAL -	STANDARD COLOR CODE +	STANDARD COLOR CODE -	Ω/DOUBLE FOOT 20 AWG	SEEBECK COEFFICIENT S(μV/°C)	@ T (°C)	°C STANDARD WIRE ERROR (SEE APPENDIX B)	NBS SPECIFIED MATERIAL RANGE† (°C)
B	Platinum - 6% Rhodium	Platinum - 30% Rhodium	–		0.2	6	600	4.4 to 8.6	0 to 1820*
E	Nickel - 10% Chromium	Constantan	Violet	Red	0.71	58.5	0	1.7 to 4.4	-270 to 1000
J	Iron	Constantan	White	Red	0.36	50.2	0	1.1 to 2.9	- 210 to 760
K	Nickel - 10% Chromium	Nickel	Yellow	Red	0.59	39.4	0	1.1 to 2.9	-270 to 1372
N (AWG 14)	Nicrosil	Nisil	–		–	39	600	–	0 to 1300
N (AWG 28)	Nicrosil	Nisil	–		–	26.2	0	–	-270 to 400
R	Platinum- 13% Rhodium	Platinum	–		0.19	11.5	600	1.4 to 3.8	-50 to 1768
S	Platinum - 10% Rhodium	Platinum	–		0.19	10.3	600	1.4 to 3.8	-50 to 1768
T	Copper	Constantan	Blue	Red	0.30	38	0	0.8 to 2.9	-270 to 400
W-Re	Tungsten - 5% Rhenium	Tungsten - 26% Rhenium	–		–	19.5	600	–	0 to 2320

** Type B double-valued below 42°C - curve fit specified only above 130°C*
† Material range is for 8 AWG wire; decreases with decreasing wire size

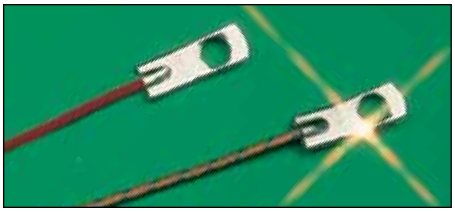


Connector: Composed of same metals as thermocouple, for minimum connection error.



Exposed Junction: Wires unprotected, faster response.
Ungrounded Junction: Best protection, electronically isolated.
Grounded Junction: WIres protected, faster response.

Thermocouple Washers: Couple built into washer; convenient mounting.



Thermocouple Well: Lower gradient, protects wire and allows user to change thermocouple without interrupting process.

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Editor's Note: Thermocouple data which conform to ITS-90 are given in "ITS-90 Thermocouple Direct and Inverse Polynomials."

OMEGA ENGINEERING, INC. gratefully acknowledges **Agilent Technologies** for permission to reproduce ***Application Note 290-Practical Temperature Measurements***.

Nicrosil/Nisil Type N Thermocouple

The Nicrosil/Nisil Type N thermocouple offers better stability than existent base-metal Types E, J, K and T. It is now available and in widespread use worldwide.

DR. NOEL A. BURLEY

The ANSI standard base-metal thermocouples, designated E, J, K and T (Ref. 1), show inherent thermoelectric instability related to time- and/or temperature-dependent instabilities in several of their physical, chemical, nuclear, structural and electronic properties. This paper reviews the major thermoelectric properties of the new nickel-base thermocouple system Nicrosil *versus* Nisil (designated type N), in which very high thermoelectric stability has been achieved by a judicious choice of elemental component concentrations.

INSTABILITY OF CONVENTIONAL BASE-METAL THERMOCOUPLES

There are three principal characteristic types and causes of thermoelectric instability in the standard base-metal thermoelement materials:

1. A gradual and generally cumulative drift in thermal EMF on long exposure at elevated temperatures. This is observed in all base-metal thermoelement materials and is mainly due to compositional changes caused by oxidation, in particular internal oxidation (Figures 1 and 2), and to neutron irradiation which can produce transmutation in nuclear reactor environments.

2. A short-term cyclic change in thermal EMF on heating in the temperature range about 250° to 650°C, which occurs in types KP (or EP) and JN (or TN and EN). This kind of EMF instability is thought to be due to some form of structural change like magnetic short-range order (Figures 3 and 4).

3. A time-independent perturbation in thermal EMF in specific temperature ranges. This is due to composition-dependent magnetic transformations which perturb the thermal EMF's in type KN in the range of about 25˚ to 225˚C (Figure 5), and in type JP above about 730˚C.

ULTRA-HIGH STABILITY OF NICROSIL/NISIL (TYPE N) THERMOCOUPLE

Nicrosil and Nisil thermocouple alloys (Ref. 2) show greatly enhanced thermoelectric stability (Ref. 3) relative to the other standard base-metal thermocouple alloys because their compositions (Table 1) are such as to virtually eliminate or substantially reduce the causes of thermoelectric instability described above. This is achieved primarily by increasing component solute concentrations (chromium and silicon) in a base of nickel above those required to cause a transition from internal to external modes of oxidation, and by selecting solutes (silicon and magnesium) which preferentially oxidize to form a diffusion-barrier, and hence oxidation inhibiting films.

The thermal EMF instabilities of the short-term cyclic kind occurring in KP and JN alloys have virtually been eliminated in nicrosil (NP) by setting the chromium content at 14.2 weight-%.

The increase in the silicon content of nisil (NN) to 4.4 weight-% has suppressed the magnetic transformation of this new alloy to below room temperature.

Virtual freedom from nuclear transmutation effects is achieved by eliminating such elements as manganese, cobalt and iron from the specified compositions of both alloys.

The very high thermoelectric stability of the Nicrosil/Nisil (type N) thermocouple is illustrated in Figures 1 and 2. The influence of thermoelement conductor cross-sectional area upon the thermal-EMF constancy of Nicrosil/Nisil is shown in Figure 6.

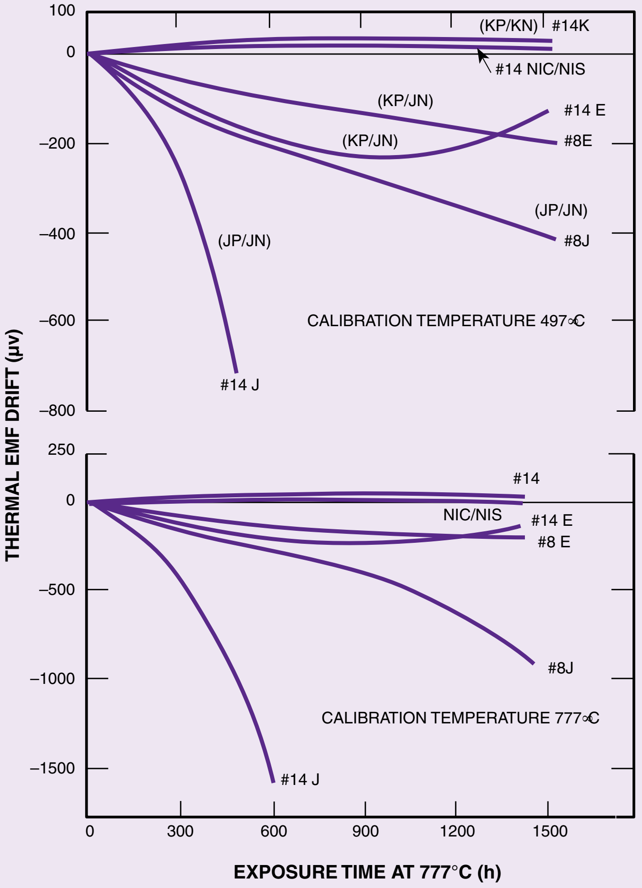


FIGURE 1. Long-term thermal-EMF drifts in air, at two calibration temperatures, for 14 AWG (#14) Nicrosil/Nisil (N) and E, J and K T/Cs. Thermal-EMF drifts for 8 AWG (#8) E and J T/Cs are also given. The drifts are changes from EMF output values existent after 20 hrs of exposure at constant aging temperature of 777°C (Ref. 3).

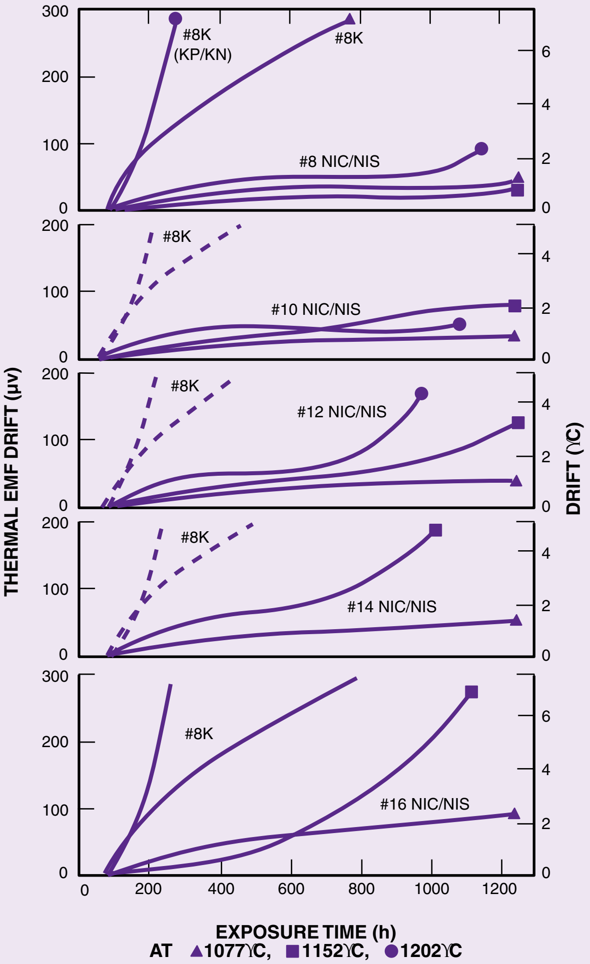
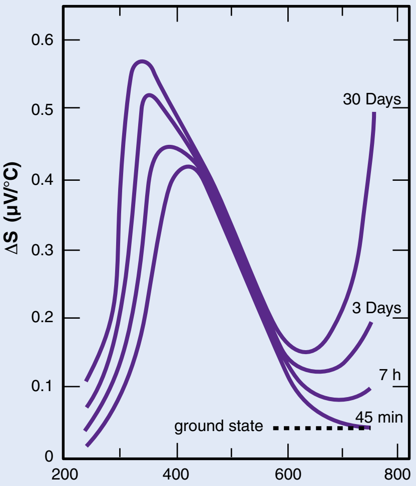


FIGURE 2. Long-term thermal-EMF drifts in air, at three constant aging (and calibration) temperatures for Nicrosil/Nisil T/Cs in five wire gauges (#). Corresponding thermal-EMF drifts for 8 AWG (#8) type K T/Cs at two of these temperatures are also given. The drifts are changes from EMF output values existent after 80 hours of exposure at the constant aging temperature (Ref. 3).

As Figure 2 shows, 8 AWG type K thermocouples appear to be markedly more unstable as temperatures progressively exceed about 1050°C. In contrast, it is clear from Figure 6 that type N thermocouples, in a range of wire sizes finer than 8 AWG, can be used reliably for extended periods of time at temperatures up to at least 1200°C. Indeed, it has recently been demonstrated (Ref. 4) that, in oxidizing atmospheres, the thermoelectric stability of the Nicrosil/Nisil thermocouple, in wire sizes not finer than 10 AWG, is about the same as that of the noble-metal thermocouples of ANSI types R and S up to about 1200°C.

Type N Thermocouple



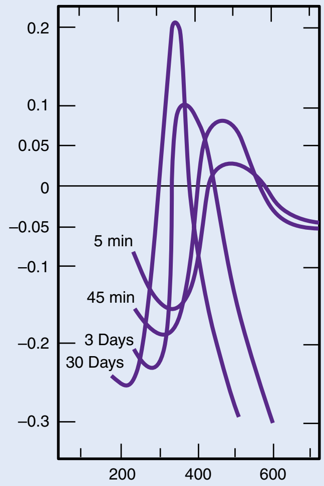


FIGURE 3 (Left). Changes in the Seebeck coefficient (ΔS) of a typical type KP thermoelement vs. platinum on initial heating, as a function of constant aging temperature for the indicated times (Ref. 3).

FIGURE 4 (Right). Similar changes of a type JN thermoelement (Ref. 3).

TABLE.1- NOMINAL COMPOSITIONS OF ANSI STANDARD BASE-METAL THERMOELEMENT ALLOYS, AND NICROSIL AND NISIL ALLOYS

ALLOY ANSI (1) DESIGNATION	CHEMICAL COMPOSITION (WEIGHT-%) Cr	Si	Mn	Al	Co	Mg	Cu	Ni	Fe
(+)KP, EP	9.5	0.4						bal	
(-)KN		1.0	3.0	2.0	0.4	0.015		bal	
(+)JP			0.3						bal
(-)JN, EN, TN			1.0		0.5		54	44	0.5
(+)TP							100		
(+)NP (nicrosil)	14.2	1.4						bal	
(-)NN (nisil)		4.4				0.10		bal	

TABLE 2-VARIANTS OF TYPE KN

ALLOY	CHEMICAL COMPOSITION (WEIGHT-%) Mn	Al	Si	co	Ni
KN1	3.02	1.90	1.19	0.41	balance
KN2	1.67	1.25	1.56	0.72	balance
KN3	-	-	2.50	1.00	balance
KN4	0.43	-	2.39	0.23	balance

PROMULGATION AS A STANDARD

No new thermocouple will survive for universal adoption and use unless it is formally promulgated by national standards authorities around the world. It is fortunate that the Nicrosil/Nisil thermocouple system is in vigorous process of being so promulgated.

The ASTM, through its Committee E-20 on Temperature Measurement, has shown considerable interest in Nicrosil *versus* Nisil, and has kept matters relating to the development, availability and use of the new thermocouple under continual review.

Recently, relevant subcommittees of ASTM E-20 have produced several publications containing information on the properties and characteristics of the Nicrosil *versus* Nisil thermocouple. A document quoting several of the EMF-temperature tables from NBS Monograph 161 (Ref. 2) was published (Ref. 6) for information. A formal ASTM Standard (E1223) is promulgated, while Type N data is now included in ASTM Standard E230. Again, in the recently published third edition of the ASTM Manual on the Use of Thermocouples (Ref. 8), various properties and characteristics of Nicrosil *versus* Nisil are summarized.

Based mainly on the above information, several crucial actions now have been taken by the supreme standardizing bodies in several important countries:

1. The Instrument Society of America (ISA), in October 1983, promulgated the Nicrosil/Nisil system as a U.S. Standard Thermocouple bearing the letter-designation “type N.”

2. The British Standards Institute (BSI) has recently promulgated a standard on the type N thermocouple identified as B.S.4937: Part 8.

3. The Japan Society for the Promotion of Science, through its Committee TC19 (Temperature), is nearing the conclusion of its deliberation on type N, leading to the issue of a Japan Industrial Standard (JIS).

These actions have ensured that the type N thermocouple and its allied pyrometric instrumentation and ancillary circuitry elements are now commercially available in a number of major countries around the world.

DISCUSSION

The various types of thermoelectric instability described in this paper can cause substantial changes in thermoelectromotive force and, hence, calibration in ANSI-standard letter-designated base-metal thermocouples types E, J, K and T. In the case of Nicrosil/Nisil, however, thermoelectric instability due to these causes is virtually eliminated or substantially attenuated over the entire temperature range up to 1230˚C. ANSI-standard base-metal thermocouples types E, J, K and T can, therefore, be regarded as obsolescent. Their replacement by Nicrosil/Nisil thermocouples would lead, in most cases, to demonstrable technological and economic advantages for science and industry at large. Indeed, the enhanced calibration stability and longevity of the type N thermocouple, taken into account with its ability to operate at considerably higher upper operating temperatures than conventional base-metal thermocouples, make it ideally suited to scientific, technological and industrial applications where temperature measurements are critical.

Use of type N thermocouples in several countries has already demonstrated a number of advantages: enhanced pyrometric accuracy, improved product quality and performance, lower reject rates, enhanced energy utilization, lower pyrometric maintenance costs, and improved productivity.

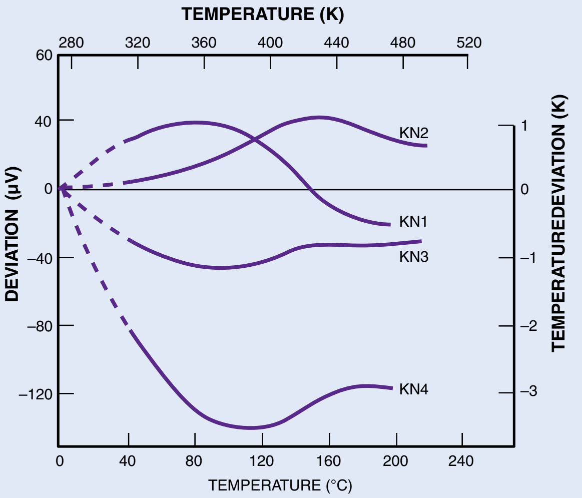


FIGURE 5. Deviations of the measured values of the thermal EMFs of several type KN thermoelements vs. platinum from reference table values (Ref. 5). Variants of type KN are given in table 2.

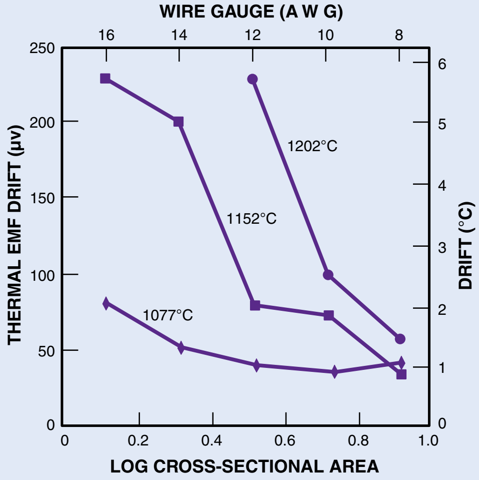


FIGURE 6. Relationship between total thermal EMF drift (after 1000 hrs of exposure in air at each of three test temperatures) and crosssectional area of Nicrosil/Nisil T/C wires. The drifts are changes from EMF output values existent after 80 hours of exposure (Ref. 3).

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**The NBS is now NIST (National Institute of Standards and Technology).*

Courtesy of Measurements and Control,

The Choice Of Sheathing For Mineral Insulated Thermocouples

H.L. Daneman, P.E.

INTRODUCTION

The mineral-insulated integrally metal-sheathed (MIMS) form of thermocouple consists of matched thermocouple wires surrounded by insulating material (typically MgO) compacted by rolling, drawing or swaging until the sheath is reduced in diameter. The advantages of MIMS thermocouples are:

- Chemical isolation of wires from the surrounding atmosphere.
- Shielding of thermoelements from sources of electrical interference.
- Protection of the wires and insulation from damage due to shock.
- Flexibility of the final assembly allowing bending.

For two decades, people have credited MIMS construction with a greater capability than deserved. Quite frequently, this form has shown less stability, less durability and lower temperature limits than corresponding unsheathed elements. The nickel bearing MIMS thermocouples used above 400°C (750°F) are especially vulnerable to calibration instability and shortened lifetime - factors which bear heavily on thermocouple use and selection.

HYSTERESIS

Thermoelectric hysteresis is one contributor toward calibration instability. Hysteresis is a form of short-range order/disorder phenomenon occurring between 200 and 600°C (peaking at ≈ 400°C) for Ni-Cr alloys such as Type K. It is evidenced by a calibration change of several degrees as the thermocouple temperature is cycled within this temperature band. Type N thermocouples exhibit hysteresis of up to 5°C when heated and cooled between 200 and 1000°C (peaking around 750°C). At 900°C hysteresis is 2 to 3°C. If the type K thermocouple, for example, will be used below 500°C, hysteresis can be reduced by annealing overnight at 450°C.

OXIDATION

Another phenomenon affecting calibration is oxidation. Ni-Cr-Al alloys (*e.g.*, Chromel*) have limited life in air above 500°C because of oxidation. A special form of oxidation is so-called "green rot" which is preferential oxidation of Cr in atmospheres with low oxygen content (*e.g.*, sheaths in which the volume of air is limited and stagnant). Nicrosil resists oxidation up to about 1,250°C (2,300°F) and does not exhibit green rot.

Several new sheath materials called "Nicrobell" (**) consist of Nicrosil with 1.5% or 3.0% niobium. Nicrobell "A" is particularly formulated to be resistant to oxidation. Another new oxidation resistant sheath material called Nicrosil $^+$ (***) consists of Nicrosil plus 0.15% magnesium. It is reported (ref. 4) to exhibit less spalling and probably have a longer life than some Nicrobell version(s) tested.

Nicrosil, itself, does not have satisfactory resistance to reducing atmospheres, such as encountered in most combustion or many heat treating processes. Other adaptations of Nicrosil for use as sheath material (such as Nicrobells B, C and D) can be expected to deal with typical nonoxidizing atmospheres.

CONTAMINATION

A third influence on calibration stability is contamination. The idea behind the mineral-insulated, integrally designed, metal-sheathed thermocouple is that the uniform compression of finely divided mineral oxides (typically MgO) insulation surrounding the wires and filling the sheath would seal the internal volume, thereby eliminating contamination. The volume of the insulation compressed by swaging, rolling or drawing is on the order of 85% of solid material. This is useful, permitting the tubing to be bent and also permitting the manufacture of smaller diameter assemblies. It does, however, permit the intrusion of gas such as water vapor or air. It also permits vapor diffusion of elements composing the wires or sheath. Bentley and Morgan determined that the vapor-phase diffusion of Mn (manganese) through the MgO insulation has the greatest influence on thermocouple decalibration.

METAL FATIGUE

Metal fatigue is another cause of shortened thermocouple life. Differing temperature coefficients of linear expansion between sheaths and wires causes strain during heating or cooling. These strains result in eventual fracture due to metal fatigue. On heating to 900°C, the thermal expansion of Nisil differs from SS 304 by 0.4% of length. Nicrosil has only 0.05% difference in thermal expansion compared to Nisil (the leg most likely to fracture). A sheath of Nicrosil, Nicrosil $^+$ or Niobell would therefore induce less metal fatigue in either leg of the Type N thermocouple than would stainless steel.

COMPOSITION

Composition changes in SS sheathed couples are generally greater than in Inconel (****) sheathed couples. In tests performed by Anderson, *et al.*, the KN leg showed an increase in chromium but a decrease in aluminum. These changes in composition contributed the major portion of the resulting change in calibration of the thermocouple.

Most stainless steels have from 1 to 2% of manganese. Type 304 has ≈ 2% manganese. Others have manganese concentrations varying from 1% to 10%. Inconel has up to 1% Mn. As a rule of thumb, each 1% of Mn in the sheath material contributes -10°C calibration shift for 1,000 hours at 1,100°C. According to Bentley, at 1,200°C, Type N in a 3 mm diameter SS sheath drifted -24°C in 1,000 hours.

HUMIDITY

There is a multiple effect of water vapor within the sheath. It is rapidly absorbed in the MgO, reducing the insulation resistance. Humidity intrusion can ruin a MIMS thermocouple assembly in as short a time as a few minutes. In lesser amounts, it destroys a protective oxide coating on Nickel-Chromium alloys, subjecting them to more rapid deterioration. The changes due to

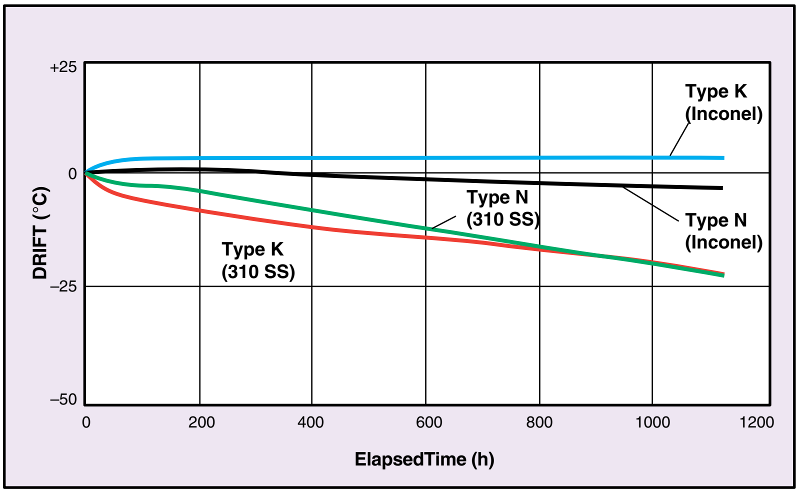

Figure 1. Drift of 3 mm diameter stainless steel sheathed and Inconel 600 sheathed type K and Nicrosil vs. Nisil thermocouples in 1200∞C in vacuum. The dips in the drift curve are the result of the "in-place inhomogeneity test" where the samples were extracted from the furnace by 5 cm.

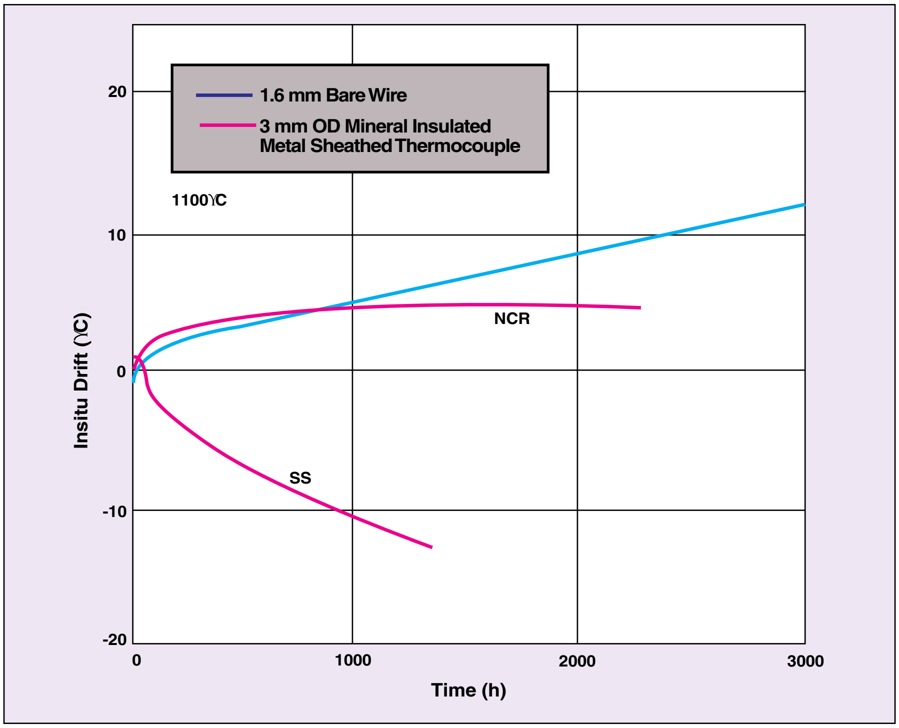

Figure 2. The insitu drift in type N thermocouples with tips held at 1100°C. Curves refer to mineral insulated metal sheathed thermocouples with 3mm OD sheaths of 310 stainless steel (SS) or Nicrosil (NCR) and 1.6mm bare wire thermocouples in air. The range in drift for the latter is also indicated.

water vapor can be sufficiently severe as to make affected couples useless by reducing insulation resistance. This reduced resistance can result in misleading temperature readings, premature failure or even erroneous readings after open circuiting.

Water vapor can be introduced during thermocouple fabrication or repair, or even by changes in atmospheric pressure during air shipment or during long periods of storage (e.g., six months) at construction sites. Care must be taken of hermetic seals during shipment and installation.

RECOMMENDATIONS

Although not mentioned above , there is some relationship between the diameter of these thermocouple materials and stability and longevity at elevated temperatures. The surface of the brickwork on which electrical heaters are supported becomes conductive at elevated temperatures. This leads to flow of electrical currents through thermocouple sheaths to ground, perhaps through the measuring instrument.

The temptation to use the finest sheathed thermocouples (as fine as 1 mm) should be resisted for higher temperature or corrosive industrial environments.

Stainless steel is a poorer sheath for mineral-insulated, metal-sheathed thermocouples than either Inconel 600 or modified Nicrosil when used with Ni-Cr thermocouples such as Type K or Type N. The modified Nicrosil sheathed thermocouples offer improved oxidation resistance up to 1,100°C (1,200 to 1,250°C for Type N), reduced failures due to differential thermal expansion, improved ductility and the elimination of the drift problems caused by the vapor diffusion of manganese from stainless steels or Inconel.

Considering the current state of supply of the newer materials, one could well choose a low manganese (0.3% or less) Inconel sheathed Type K MIMS thermocouple until such time as modified Nicrosil sheathed Type K or N and appropriate supporting data become readily available.

(*) CHROMEL is a trademark of the Hoskins Manufacturing Co.

(**) NICROBELL is a trademark of NICROBELL Pty. Ltd. NICROBELL sheath alloys are patented in a number of countries including the USA

(***) NICROSIL + is a trademark of Pyrotenax Australia Pty. Ltd.

(****) INCONEL is a trademark of the International Nickel Co.

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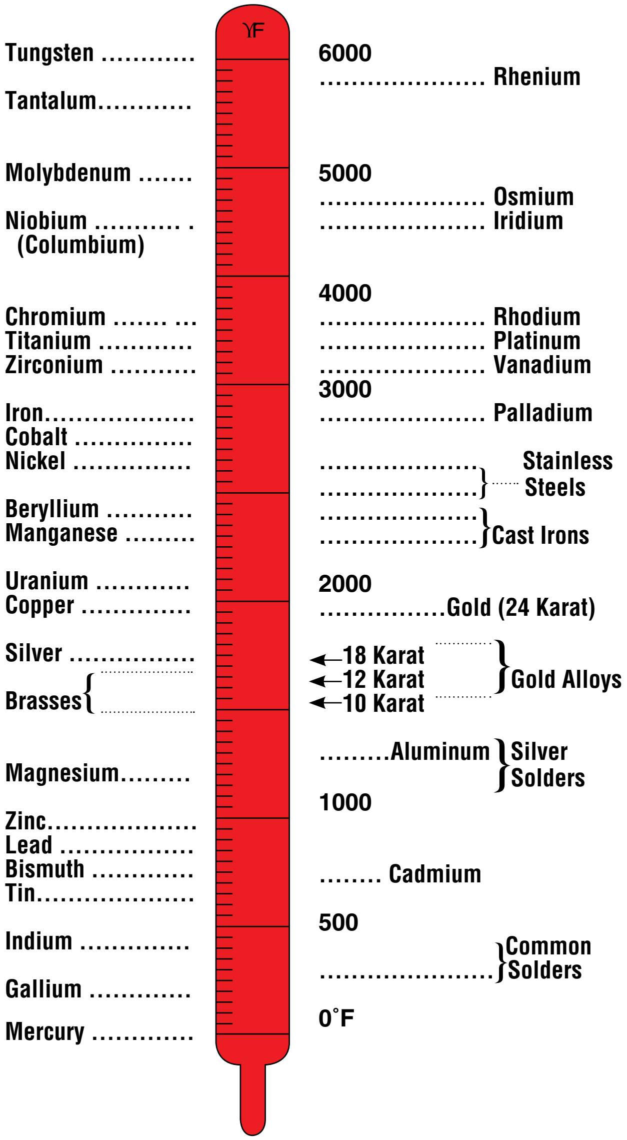
Material Selection Guide

This chart is a guide to selection of thermocouple sheath and thermowell materials according to process fluid. It includes factors such as catalytic reaction, contamination and electrolysis. However, there are many instances where factors other than these must be considered. It is recommended that such special applications be submitted to OMEGA ENGINEERING for recommendations. These recommendations are only guides based on the most economical material selection. OMEGA ENGINEERING cannot be held responsible if these recommendations are not satisfactory for specific applications.

Substance	Conditions	Recommended Metal
Acetate Solvents	Crude or Pure	Monel or Nickel
Acetic Acid	10% - 21°C (70°F)	304 Stainless Steel
“ “	50% - 21°C (70°F)	304 Stainless Steel
“ “	50% - 100°C (212°F)	316 Stainless Steel
“ “	99% - 21°C (70°F)	430 Stainless Steel
“ “	99% - 100°C (212°F)	430 Stainless Steel
Acetic Anhydride		Monel
Acetone	100°C (212°F)	304 Stainless Steel
Acetylene		304, Monel, Nickel
Alcohol Ethyl	21°C (70°F)	304 Stainless Steel
“ “	100°C (212°F)	304 Stainless Steel
Alcohol Methyl	21°C (70°F)	304 Stainless Steel
“ “	100°C (212°F)	304 Stainless Steel
Aluminum	Molten	Cast iron
Aluminum Acetate	Saturated	304 Stainless Steel
Aluminum Sulphate	10% - 21°C (70°F)	304 Stainless Steel
“ “	Saturated 21°C (70°F)	304 Stainless Steel
“ “	10% - 100°C (212°F)	316 Stainless Steel
“ “	Saturated 100°C (212°F)	316 Stainless Steel
Ammonia	All concentrations 21°C (70°F)	304 Stainless Steel
Ammonium Chloride	All concentrations 100°C (212°F)	316 Stainless Steel
Ammonium Nitrate	All concentrations 21°C (70°F)	304 Stainless Steel
“ “	All concentrations 100°C (212°F)	304 Stainless Steel
Ammonium Sulphate	5% - 21°C (70°F)	304 Stainless Steel
“ “	10% - 100°C (212°F)	316 Stainless Steel
“ “	Saturated 100°C (212°F)	316 Stainless Steel
Aniline	All concentrations 21°C (70°F)	304 Stainless Steel
Amylacetate		Monel
Asphalt		Steel (C1018) Phosphor Bronze, Monel, Nickel
Barium Carbonate	21°C (70°F)	304 Stainless Steel
Barium Chloride	5% - 21°C (70°F)	Monel
“ “	Saturated 21°C (70°F)	Monel
“ “	Aqueous - Hot	316 Stainless Steel
Barium Hydroxide		Steel (C1018)
Barium Sulphite		Nichrome
Benzaldehyde		Steel (C1018)
Benzene	21°C (70°F)	304 Stainless Steel
Benzine		Steel (C1018), Monel, Inconel
Benzol	Hot	304 Stainless Steel
Boracic Acid	5% Hot or Cold	304 Stainless Steel
Bromine	21°C (70°F)	Tantalum
Butadiene		Brass, 304
Butane	21°C (70°F)	304 Stainless Steel
Butylacetate		Monel
Butyl Alcohol		Copper
Butylenes		Steel (C1018), Phosphor Bronze
Butyric Acid	5% - 21°C (70°F)	304 Stainless Steel
“ “	5% - 66°C (150°F)	304 Stainless Steel
Calcium Bisulfite	21°C (70°F)	316 Stainless Steel
Calcium Chlorate	Dilute 21°C (70°F)	304 Stainless Steel
“ “	Dilute 66°C (150°F)	304 Stainless Steel
Calcium Hydroxide	10% - 100°C (212°F)	304 Stainless Steel
“ “	20% - 100°C (212°F)	304 Stainless Steel
“ “	50% - 100°C (212°F)	317 Stainless Steel
Carbolic Acid	All 100°C (212°F)	316 Stainless Steel
Carbon Dioxide	Dry	Steel (C1018), Monel
“ “	Wet	Aluminum,Monel,Nickel
Carbon Tetrachloride		10% - 70°F, Monel
Chlorex Caustic		316SS, 317SS
Chlorine Gas	Dry 21°C (70°F)	317 Stainless Steel
“ “	Moist 21°C (70°F)	Hastelloy C
“ “	Moist 100°C (212°F)	Hastelloy C
Chromic Acid	5% - 21°C (70°F)	304 Stainless Steel
“ “	10% - 100°C (212°F)	316 Stainless Steel
“ “	50% - 100°C (212°F)	316 Stainless Steel
Citric Acid	15% - 21°C (70°F)	304 Stainless Steel
“ “	15% - 100°C (212°F)	316 Stainless Steel
“ “	Concentrated 100°C (212°F)	317 Stainless Steel
Coal Tar	Hot	304 Stainless Steel
Coke Oven Gas		Aluminum
Copper Nitrate		304, 316
Copper Sulphate		304, 316
Core Oils		316 Stainless Steel
Cottonseed Oil		Steel (C1018), Monel, Nickel
Creosols		304 Stainless Steel
Creosote Crude		Steel (C 1018), Monel, Nickel
Cyanogen Gas		304 Stainless Steel
Dowtherm		Steel (C1018)
Epsom Salt	Hot and Cold	304 Stainless Steel
Ether	21°C (70°F)	304 Stainless Steel
Ethyl Acetate		Monel
Ethyl Chloride	21°C (70°F)	304 Stainless Steel
Ethylene Glycol		Steel (C1018)
Ethyl Sulphate	21°C (70°F)	Monel
Ferric Chloride	1% - 21°C (70°F)	316 Stainless Steel
“ “	5% - 21°C (70°F)	Tantalum
“ “	5% - Boiling	Tantalum
Ferric Sulphate	5% - 21°C (70°F)	304 Stainless Steel
Ferrous Sulphate	Dilute 21°C (70°F)	304 Stainless Steel
Formaldehyde		304 Stainless Steel
Freon		Steel (C1018)
Formic Acid	5% - 21°C (70°F)	316 Stainless Steel
“ “	5% - 66°C (150°F)	316 Stainless Steel
Gallic Acid	5% - 21°C (70°F)	Monel
“ “	5% - 66°C (150°F)	Monel
Gasoline	21°C (70°F)	304 Stainless Steel
Glucose	21°C (70°F)	304 Stainless Steel
Glycerine	21°C (70°F)	304 Stainless Steel
Glycerol		304 Stainless Steel
Heat Treating		446 Stainless Steel
Hydrobromic Acid	48% - 100°C (212°F)	Hastelloy B
Hydrochloric Acid	1% - 21°C (70°F)	Hastelloy C
“ “	1% - 100°C (212°F)	Hastelloy B
“ “	5% - 21°C (70°F)	Hastelloy C
“ “	5% - 100°C (212°F)	Hastelloy B
“ “	25% - 21°C (70°F)	Hastelloy B
“ “	25% - 100°C (212°F)	Hastelloy B
Hydrocyanic Acid		316 Stainless Steel
Hydrofluoric Acid		Hastelloy C
Hydrogen Peroxide	21°C (70°F)	316 Stainless Steel
“ “	100°C (212°F)	316 Stainless Steel
Hydrogen Sulphide	Wet and dry	316 Stainless Steel
Iodine	21°C (70°F)	Tantalum
Kerosene	21°C (70°F)	304 Stainless Steel
Lactic Acid	5% - 21°C (70°F)	304 Stainless Steel
“ “	5% - 66°C (150°F)	316 Stainless Steel
“ “	10% - 100°C (212°F)	Tantalum
Lacquer	21°C (70°F)	316 Stainless Steel
Latex		Steel (C1018)
Lime Sulphur		Steel (C1018), 304, Monel
Linseed Oil	21°C (70°F)	304 Stainless Steel
Magnesium Chloride	5% - 21°C (70°F)	Monel
“ “	5% - 100°C (212°F)	Nickel
Magnesium Sulphate		Cold and Hot Monel
Malic Acid	Cold and Hot	316 Stainless Steel
Mercury		Steel (C1018), 304, Monel
Methane	21°C (70°F)	Steel (1020)
Milk		304, Nickel
Mixed Acids (Sulphuric and Nitric - all temp. and %)		Carpenter #20
Molasses		Steel (C1018), 304, Monel, Nickel
Muriatic Acid	21°C (70°F)	Tantalum
Nap	21°C (70°F)	304 Stainless Steel
Natural Gas	21°C (70°F)	304 Stainless Steel
Neon	21°C (70°F)	304 Stainless Steel
Nickel Chloride	21°C (70°F)	304 Stainless Steel
Nickel Sulphate	Hot and Cold	304 Stainless Steel
Nitric Acid	5% - 21°C (70°F)	304 Stainless Steel
“ “	20% - 21°C (70°F)	304 Stainless Steel
“ “	50% - 21°C (70°F)	304 Stainless Steel
“ “	50% - 100°C (212°F)	304 Stainless Steel
“ “	65% - 100°C (212°F)	316 Stainless Steel
“ “	Concentrated - 21°C (70°F)	304 Stainless Steel
“ “	Concentrated - 100°C (212°F)	Tantalum
Nitrobenzene	21°C (70°F)	304 Stainless Steel
Nitrous Acid		304 Stainless Steel
Oleic Acid	21°C (70°F)	316 Stainless Steel
Oleum	21°C (70°F)	316 Stainless Steel
Oxalic Acid	5% - Hot and Cold	304 Stainless Steel
“ “	10% - 100°C (212°F)	Monel
Oxygen	21°C (70°F)	Steel (C1018)
“	Liquid	304 Stainless Steel
Palmitic Acid		316 Stainless Steel
Petroleum Ether		
Phenol		304 Stainless Steel
Pentane		304 Stainless Steel
Phosphoric Acid	1% - 21°C (70°F)	304 Stainless Steel
“ “	5% - 21°C (70°F)	304 Stainless Steel
“ “	10% - 21°C (70°F)	316 Stainless Steel
“ “	10% - 100°C (212°F)	Hastelloy C
“ “	30% - 21°C (70°F)	Hastelloy B
Picric Acid	21°C (70°F)	304 Stainless Steel
Potassium Bromide	21°C (70°F)	316 Stainless Steel
Potassium Carbonate	1% - 21°C (70°F)	304 Stainless Steel
Potassium Chlorate	21°C 21°C (70°F)	304 Stainless Steel
Potassium Chloride	5% - 21°C (70°F)	304 Stainless Steel
“ “	5% - 100°C (212°F)	304 Stainless Steel
Potassium Hydroxide	5% - 21°C (70°F)	304 Stainless Steel
“ “	25% - 100°C (212°F)	304 Stainless Steel
“ “	50% - 100°C (212°F)	316 Stainless Steel
Potassium Nitrate	5% - 21°C (70°F)	304 Stainless Steel
“ “	5% - 100°C (212°F)	304 Stainless Steel
Potassium Permanganate	5% - 21°C (70°F)	304 Stainless Steel
Potassium Sulphate	5% - 21°C (70°F)	304 Stainless Steel
“ “	5% - 100°C (212°F)	304 Stainless Steel
Potassium Sulphide	21°C (70°F)	304 Stainless Steel
Propane		304 Stainless Steel
Pyrogallic Acid		304 Stainless Steel
Quinine Bisulphate	Dry	316 Stainless Steel
Quinine Sulphate	Dry	304 Stainless Steel
Resin		304 Stainless Steel
Rosin	Molten	304 Stainless Steel
Sea Water		Monel
Salommoniac		Monel
Salicylic Acid		Nickel
Shellac		304 Stainless Steel
Soap	21°C (70°F)	304 Stainless Steel
Sodium Bicarbonate	All concentrations 21°C (70°F)	304 Stainless Steel
“ “	5% - 66°C (150°F)	304 Stainless Steel
Sodium Bisulphate		Monel
Sodium Carbonate	5% - 21°C (70°F)	304 Stainless Steel
“ “	5% - 66°C (150°F)	304 Stainless Steel
Sodium Chloride	5% - 21°C (70°F)	316 Stainless Steel
“ “	5% - 66°C (150°F)	316 Stainless Steel
“ “	Saturated - 21°C (70°F)	316 Stainless Steel
“ “	Saturated - 100°C (212°F)	316 Stainless Steel
Sodium Fluoride	5% - 21°C (70°F)	Monel
Sodium Hydroxide		304 Stainless Steel
Sodium Hypochlorite		5% still
316 Stainless Steel		
Sodium Nitrate	Fused	317 Stainless Steel
Sodium Peroxide		304 Stainless Steel
Sodium Phosphate		Steel (C1018)
Sodium Silicate		Steel (C1018)
Sodium Sulphate	21°C (70°F)	304 Stainless Steel
Sodium Sulphide	21°C (70°F)	316 Stainless Steel
Sodium Sulphite	66°C (150°F)	304 Stainless Steel
Steam		304 Stainless Steel
Stearic Acid		304 Stainless Steel
Sulphur Dioxide	Moist Gas - 21°C (70°F)	316 Stainless Steel
“ “	Gas - 300°C (575°F)	304 Stainless Steel
Sulphur	Dry - Molten	304 Stainless Steel
“	Wet	316 Stainless Steel
Sulphuric Acid	5% - 21°C (70°F)	Carp. 20, Hastelloy B
“ “	5% - 100°C (212°F)	Carp. 20, Hastelloy B
“ “	10% - 21°C (70°F)	Carp. 20, Hastelloy B
“ “	10% - 100°C (212°F)	Carp. 20, Hastelloy B
“ “	50% - 21°C (70°F)	Carp. 20, Hastelloy B
“ “	50% - 100°C (212°F)	Carp. 20, Hastelloy B
“ “	90% - 21°C (70°F)	Carp. 20, Hastelloy B
“ “	90% - 100°C (212°F)	Hastelloy D
Tannic Acid	70˚F	304 Stainless Steel
Tar		Steel (C1018), 304, Monel, Nickel
Tartaric Acid	21°C (70°F)	304 Stainless Steel
“ “	66°C (150°F)	316 Stainless Steel
Tin	Molten	Cast Iron
Tolvene		Aluminum, Phosphor Bronze, Monel
Trichloroethylene		Steel (C1018)
Turpentine		304 Stainless Steel
Varnish		304 Stainless Steel
Vegetable Oils		Steel (C1018), 304, Monel
Vinegar		304 Stainless Steel
Water	Fresh	Copper, Steel (C1018), Monel
“	Salt	Aluminum
Whiskey, Wine		304, Nickel
Xylene		Copper
Zinc	Molten	Cast Iron
Zinc Chloride		Monel
Zinc Sulphate	5% - 21°C (70°F)	304 Stainless Steel
“ “	Saturated - 21°C (70°F)	304 Stainless Steel
“ “	25% - 100°C (212°F)	304 Stainless Steel

Melting Temperatures of Some Important Metals

Approximate melting points are given only as a guide for material selection since many factors including atmosphere, type of process, mounting, etc., all affect the operating maximum.



Very High Temperature Sheath Materials

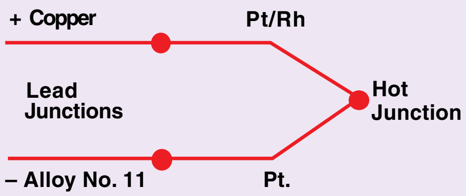
Sheath Material	Rec. Useful Temp.	Melting Point	Environmental Conditions			
			Oxidizing	Hydrogen	Inert	Vacuum
Molybdenum	4000°F	4730°F	Not Rec.	Fair	Fair	Good
Tantalum	4500°F	5425°F	Not Rec.	Not Rec.	Not Rec.	Good
Platinum	3050°F	3223°F	Very Good	Poor	Poor	Poor

Thermometry Fixed Points

THERMOELECTRIC FIXED POINT	MELTING POINTS FROM THE PRACTICAL INTERNATIONAL TEMPERATURE SCALE IPTS-68	
Boiling point of oxygen	-183.0 °C	-297.3 °F
Sublimation point of carbon dioxide	- 78.5	-109.2
Freezing point of mercury	- 38.9	- 38
Ice Point	0	32
Triple point of water	0.01	32
Boiling point of water	100.0	212
Triple point of benzoic acid	122.4	252.3
Boiling point of naphthalene	218	424.4
Freezing point of tin	231.9	449.4
Boiling point of benzophenone	305.9	582.6
Freezing point of cadmium	321.1	610
Freezing point of lead	327.5	621.5
Freezing point of zinc	419.6	787.2
Boiling point of sulfur	444.7	832.4
Freezing point of antimony	630.7	1167.3
Freezing point of aluminum	660.4	1220.7
Freezing point of silver	961.9	1763.5
Freezing point of gold	1064.4	1948
Freezing point of copper	1084.5	1984.1
Freezing point of palladium	1554	2829
Freezing point of platinum	1772	3222

Extension Grade Wires for Platinum and Tungsten-Rhenium Alloys

Compensating alloys made into extension wire for tungsten-rhenium thermocouples and platinum-rhodium thermocouples closely match the **emf** of the thermocouples over limited range



- The alloy 405/426 combination is used with Tungsten 5% Re vs Tungsten 26% Re.
- The alloy 200/226 combination is used with Tungsten vs Tungsten 26% Re.
- The alloy 203/225 combination is used with Tungsten 3% Re vs Tungsten 25%.
- The Combination copper/alloy #11 is used with platinum-rhodium alloys vs pure platinum.