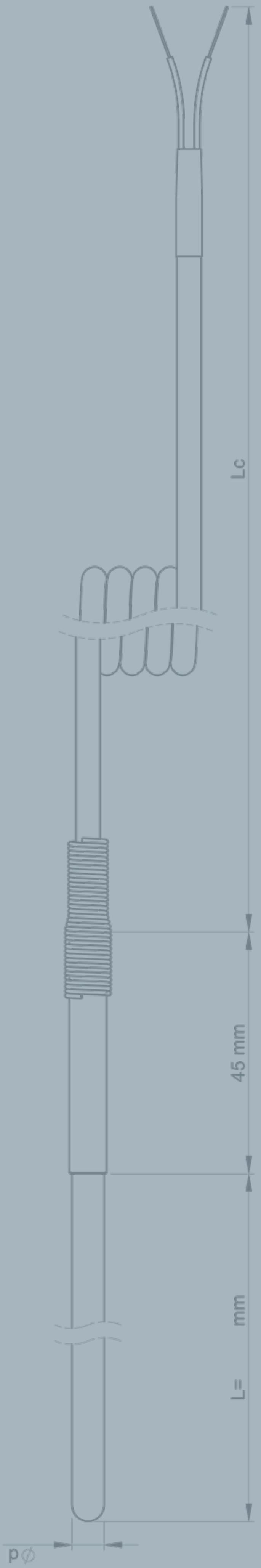
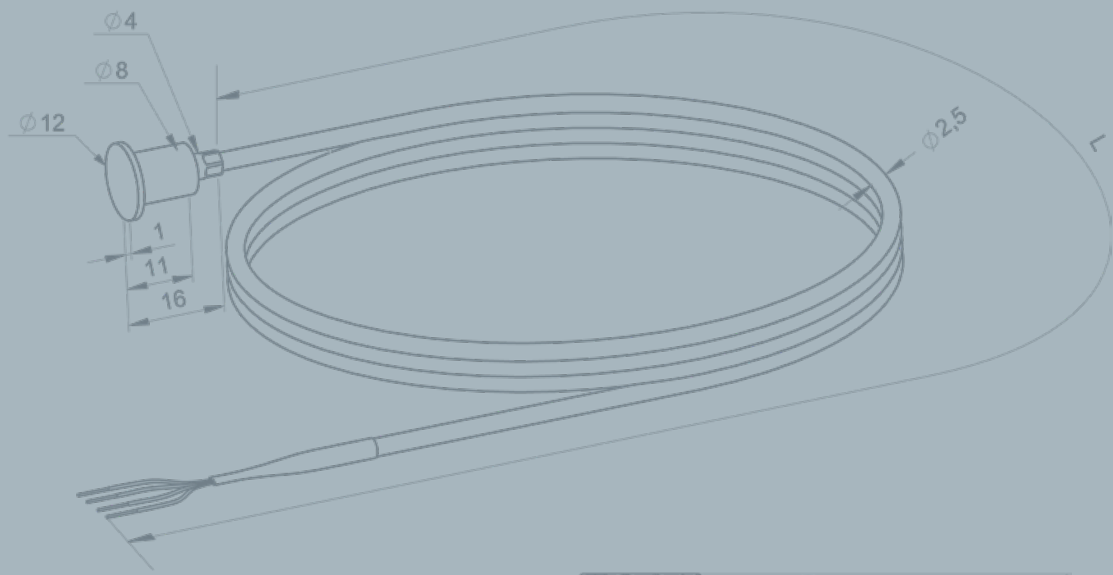
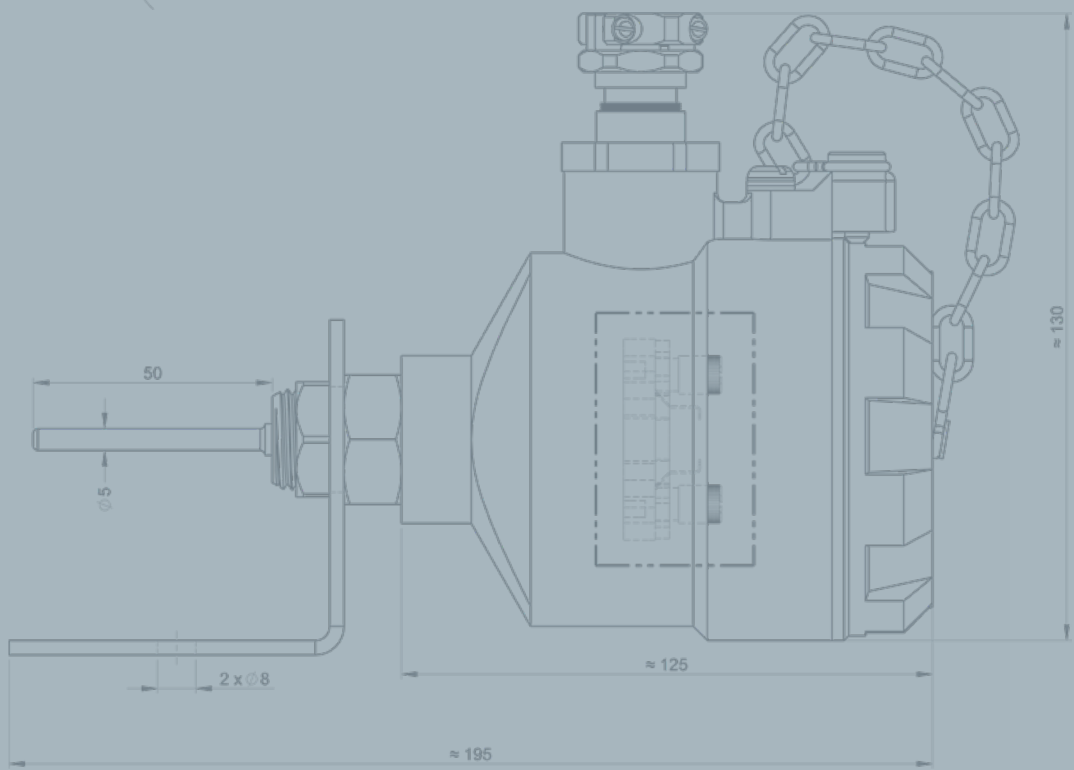
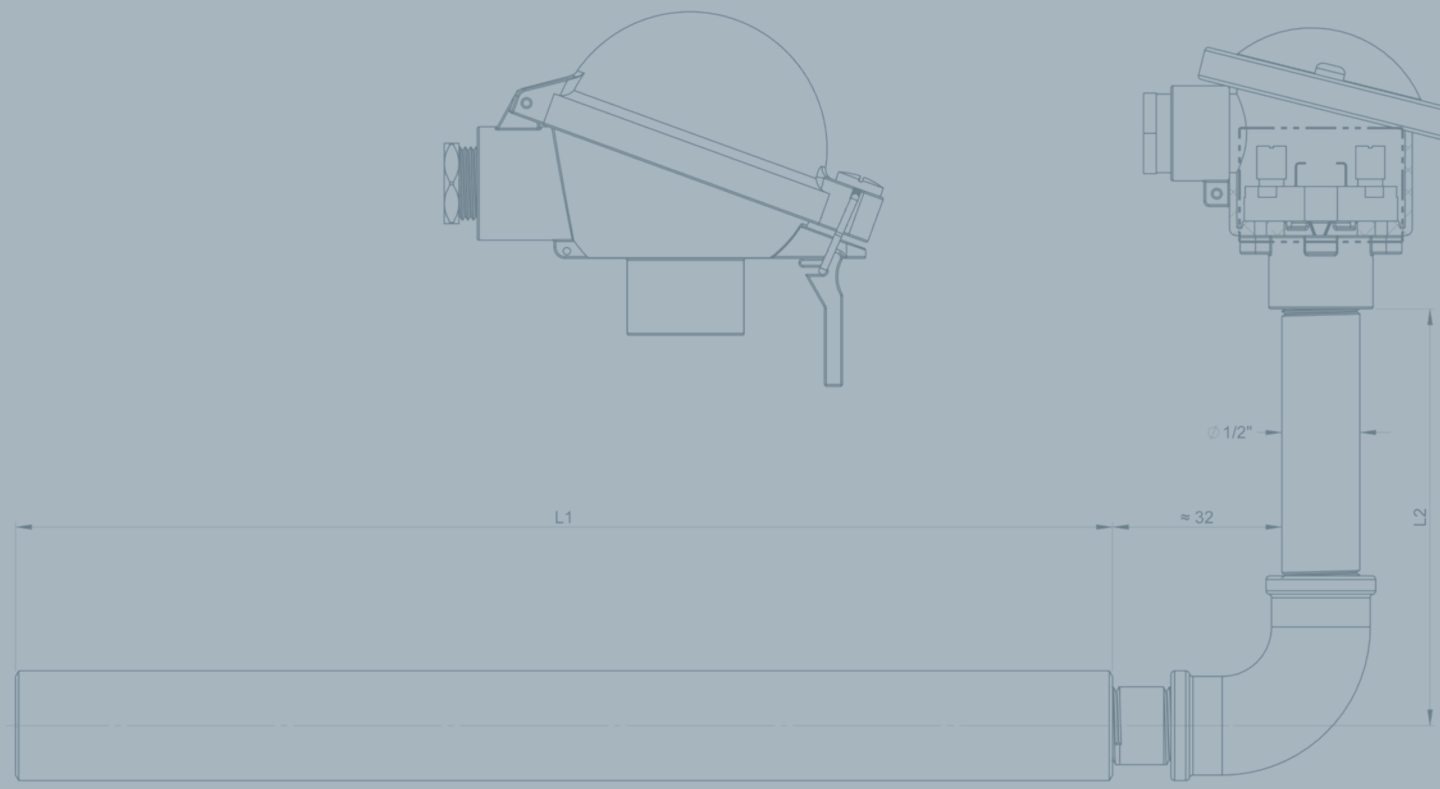






TECHNICAL GUIDE



Ø 1/2"
L1
≈ 32
L2

A - TEMPERATURE

There are several definitions of temperature, depending on the field to which it refers. For example:

Physics: Physical phenomenon occurring as a manifestation of the kinetic energy which indicates the degree of thermal agitation of the molecules in a body or a substance; arbitrary parameter used to measure this phenomenon.

Climatology: Energy state of the air leading to varying degrees of heating.

Physiology: Heat level of a human or animal body.

Temperature is therefore an intensive quantity (quantity used to describe the state of a system whose numeric value does not depend on the amount of material constituting the system), which makes it difficult to measure and encourages the use of a practical scale based on repeatable, easily identifiable physical phenomena which enables it to be monitored.

Today, the applicable scale is the **1990 international temperature scale (ITS-90).** It is the result of improved knowledge of thermometry from the first scale, dating from 1927, through to the present. It is based on fixed temperature points (themselves based on the phase transitions of pure substances), instruments (thermometers) and formulae for interpolation between the fixed points or for extrapolation. This scale necessarily evolves over time due to the improved accuracy of the fixed-point temperatures, bringing the scale value closer to the thermodynamic temperature.

It is possible to identify two categories of temperature measurement units: absolute and relative.

- **Absolute** units start from absolute zero, theoretically the lowest temperature possible. It corresponds to the point where the molecules and atoms in a system have the lowest possible thermal energy.

- **Kelvin (international system)** : represented by the letter K without any "°" degree symbol. It was created by William Thomson. This unit was included in the international system of units in 1954. The thermodynamic temperature unit (the Kelvin) is defined on the basis of the triple point of water , 273.16 K (or 0.01 °C).

- **Relative** units because they are compared with a physical and chemical process which always produces the same temperature.

- **Degrees Celsius (international system)**: also called degrees centigrade and represented by the symbol °C. This measurement unit is defined by assigning the value 0° to the freezing point of water and the value 100° to the boiling point of water when both measurements are taken at a pressure of one atmosphere. The scale is then divided into 100 equal portions in which each corresponds to 1 degree. This scale was proposed by the Swedish physicist and astronomer Anders Celsius in 1742.

- **Degrees Fahrenheit (international system)**: this measurement unit is based on divisions between the freezing and evaporation points of ammonium chloride solutions. In this way, Daniel Gabriel Fahrenheit's proposal in 1724 established the zero and hundred for the freezing and evaporation temperatures of ammonium chloride in water. He used a portable mercury thermometer into which he introduced a mixture of equal measures of crushed ice and ammonium chloride. This concentrated saline solution gave the lowest temperature possible in the laboratory at the time. He then made another mixture of crushed ice and pure water which determined the point 30 °F, later set at 32 °F (melting point of ice), and exposed the portable thermometer to the steam from boiling water to obtain the point 212 °F (boiling point of water). The difference between the two points is 180 °F which, divided into 180 equal portions, determines the degree Fahrenheit. .

ITS-90 is defined for temperatures above 0.65 K and up to the highest temperature measurable according to Planck's law for monochromatic radiation. The temperature measured with this scale (T90) is the closest to the thermodynamic temperature. This means it is universal..

ITS-90 covers several temperature ranges. For each temperature range, it therefore defines fixed temperature points and a specific instrument for measurement and interpolation between these fixed points. The fixed temperature points correspond to phase transitions in pure substances. For example, the freezing points of zinc, tin or silver, the melting point of gallium or the triple points of oxygen, mercury or water.

FIXED-POINT TEMPERATURE (IN K)	SUBSTANCE	TYPE OF POINT
3 to 5	helium	saturation vapour pressure
13.8033	hydrogen	triple
approx. 17	hydrogen (or helium)	saturation vapour pressure (or gas thermometer)
approx. 20.3	hydrogen (or helium)	saturation vapour pressure (or gas thermometer)
24.5561	neon	triple
54.3584	oxygen	triple
83.8058	argon	triple
234.3156	mercury	triple
273.16	water	triple
302.9146	gallium	melting
429.7485	indium	freezing
505.078	tin	freezing
692.677	zinc	freezing
933.473	aluminium	freezing
1,234.93	silver	freezing
1,337.33	gold	freezing
1,357.77	copper	freezing

In particular, for the most widely-encountered temperatures, ITS-90 defines :

- 14 fixed points between 13.803 K (-259.346 °C) and 1,234.93 K (+961.78 °C) and the interpolation instrument is a standard platinum resistance thermometer;
- 3 fixed points above 1,234.93 K (961.78 °C) and the temperature is measured by optical pyrometry, using Planck's radiation law by extrapolation at one of these three fixed points.

Today, temperature is the most widely-measured quantity apart from time. In industry, this quantity is particularly important. Indeed, it often conditions the quality of manufactured products. In addition, it is measured and controlled (by controllers, PLCs or other devices) to ensure safe processes and keep energy spending in check.

This means you must use sensors suited to the processes and enabling the most accurate measurement possible according to the conditions of use. There are two types of sensors widely used to perform this function.

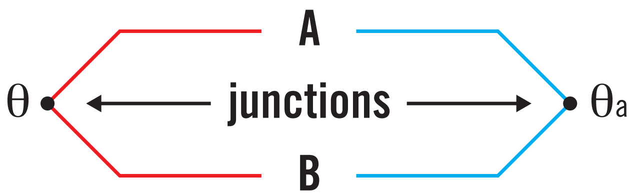
B - THERMOCOUPLES

1 - TECHNICAL OVERVIEW

The Seebeck effect (or thermo-electric effect):

The German physicist Thomas Johann Seebeck gave his name to the phenomenon which he discovered in 1821. It corresponds to the appearance of an electromotive force (emf) caused by a temperature difference between the junctions of two conductors of different types (A and B below). The emf depends on the temperature difference and the nature of the conductors used.

This is the phenomenon which is used for temperature measurement. A thermocouple is therefore composed of two wires of different metals, welded at one of their extremities. This junction is called the "hot junction" and is set up in the milieu whose temperature we are seeking to measure. The other two extremities are connected to the instrument measuring the emf produced by the thermocouple. This junction is called the "cold junction". The reference temperature of this cold junction is usually 0°C.



The thermocouple defined above is characterized by:

Its operating range

Its resolution limit, in mV/°C. This corresponds to the emf caused by a temperature difference between the two junctions.

The emf generated by this temperature difference can be calculated using the following formula:

$$\Delta V = \int_{T_{ref}}^{T_c} S_{ab}(\theta)\, d\theta$$

Tc : temperature of the milieu to be measured in which the hot junction is immersed.

Tref : temperature of the cold junction

Sab : Seebeck coefficient depending on the nature of the conductors A and B

In practice, this emf is often indicated by forcing the cold junction temperature to 0°C. For a cold junction maintained at 0 °C, the evolution of the emf as a function of the hot junction temperature is not linear. A thermocouple whose emf varies significantly can be used to perform measurements with greater sensitivity. This means the measurement is more accurate.

2 - LAWS GOVERNING THE USE OF THERMOCOUPLES

3 fundamental principles govern the thermo-electric phenomenon:

- The Seebeck effect (see above)
- The Peltier effect
- The Thompson effect

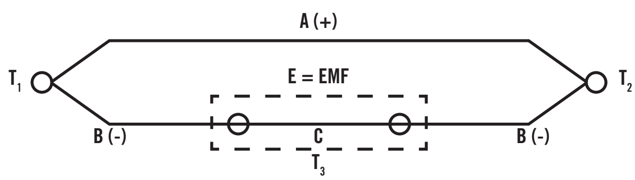
The following 3 laws are derived from these 3 principles

- Law of intermediate metals (or conductors)
- Law of homogeneous metals (or circuits)
- Law of intermediate (or successive) temperatures

Law of intermediate metals:

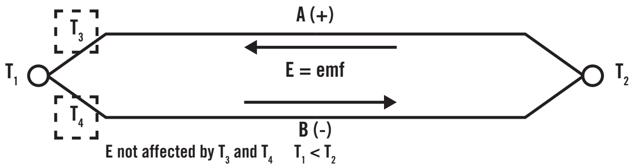
This law stipulates that a metal (a conductor of a different type) added to the thermocouple circuit has no effect on the emf produced, as long as the junctions of the metal added to the other metals are at the same temperature.

This situation is very frequent. It is the case when a voltmeter or other instrument (equivalent of a single conductor) is used: it will not modify the emf to be measured.



Law of homogeneous metals:

This law stipulates that "an electric current cannot be maintained in a circuit composed of a single homogeneous metal, whatever the variations in terms of cross-section, simply by applying heat". If a junction of two different metals is maintained at temperature T1, while the other is kept at T2, the emf effect produced is independent and not affected by the temperature distribution along the wires T3 and T4.



Law of intermediate temperatures:

In industrial installations, it is not easy to keep a thermocouple's reference junction at a constant temperature (0°C). Indeed, systems need to be implemented so that the emf produced at the level of the reference junction is equivalent to the emf which would be generated if the reference junction was kept at a standard temperature, usually 0°C.

The law of intermediate temperatures provides a means of linking the emf produced by a thermocouple in ordinary conditions to a constant standardized temperature. This law stipulates that the sum of the emf values produced by two thermocouples (one with its junctions at 0°C and at a standard reference temperature, the other with its junctions at the reference temperature and at the temperature measured) is equivalent to the emf produced by a single thermocouple with its junctions at 0°C and at the temperature measured.

Conclusion:

By combining these three fundamental laws, we can use the thermocouple to measure a temperature:

- The algebraic sum of the thermo-electric emf generated in any circuit containing homogeneous metals of different natures only varies as a function of the temperature at the level of the junction.
- If all the junctions of a circuit except one are kept at a given reference temperature, the emf generated only varies as a function of the temperature of that junction and can therefore be used to measure the temperature.

3 - THERMOCOUPLE PRODUCTION MODES

In general terms, thermocouples are very widely used in industry due to their versatility: they can be used over a very wide temperature range (up to 2,000 °C) while offering a quick response time and a long life span. They are also rugged, because they are relatively simple to build and resist shocks and vibrations. They are easy to integrate because they do not take up much space.

Nevertheless, no thermocouple is designed to meet all requirements. Many types of thermocouples are now available on the market. Each type offers advantages and drawbacks which you need to be familiar with to determine whether it is suitable for the environment in which it will be used. It is a question of finding the best compromise.

There are several production modes. They most widespread are:

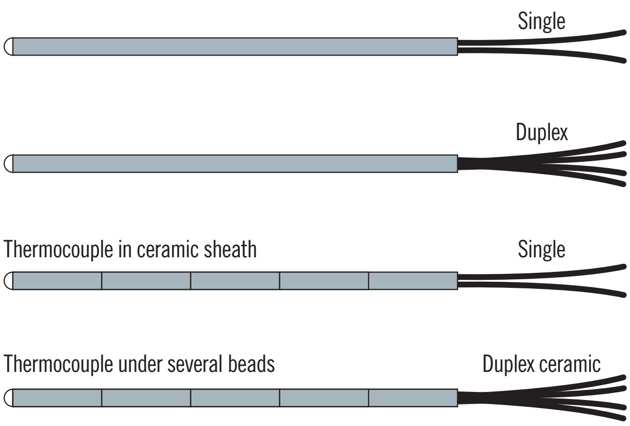
- Bare-wire thermocouples
- Thermocouples with mineral insulation

3.1 BARE-WIRE THERMOCOUPLES:

The wire thermocouple is the most basic type. It is composed of two metals of different types connected at one end in order to create a measurement junction (hot junction). The common feature shared by this type of thermocouples is that they all have one measurement junction exposed.

For most of them, the advantages are: quick response time, rugged design and use at high temperatures. The fact that the junction is exposed is nevertheless a disadvantage, as this exposure makes it sensitive to the environment (particularly in oxidizing and reducing environments). As a result, they need to be protected.

The illustration below shows the different mounting options for bare-wire thermocouples.



3.2 THERMOCOUPLES WITH MINERAL INSULATION:

To overcome the disadvantages of the wire models, thermocouples with mineral insulation can be used. The thermocouple's two wires are incorporated in a ceramic insulator and protected by a metal sheath. To ensure a long life span for the thermocouple, sheaths which protect against contamination by chemical products and known physical compounds are used.

The two main components are:

A : The material of the mineral insulation:

The table below shows the four most widely-used materials for this type of thermocouple.

INSULATION	FORMULA	MELTING POINT	MAX. TEMP. IN OXIDIZING ENVIRONMENT	RES. TO THERMAL SHOCKS	STABILITY				
					REDUCING ATM.	CARBON	ACIDIC SLAG	BASIC SLAG	METAL
Alumina	Al 2 0 3	2037°C	1954°C	Good	Good	Satisfactory	Good	Good	Good
Magnesium	MgO	2760°C	2395°C	Satisfactory	Low	Good	Low	Good	Satisfactory
Thorium dioxide	ThO 2	3315°C	2700°C	Low	Good	Satisfactory	Low	Good	Excellent
Zirconium dioxide	ZrO 2	2590°C	2510°C	Satisfactory	Good	Satisfactory	Good	Low	Good

The most important parameters to be taken into consideration when choosing mineral insulation are the maximum temperature limit and the performance levels at that temperature. Obviously, other parameters may also be taken into account, such as the resistivity, purity and fragmentation. These parameters remain secondary to the temperature, however. For example: MgO, which is the most widely-used insulator, has a maximum temperature limit of 2.395 °C, high resistivity, excellent purity and is very rugged.

B : The metal sheath

The table below shows some of the numerous materials which may be used to protect thermocouples with mineral insulation. The two most important parameters for choosing the sheath are: the operating temperature and the environment. The environment may be oxidizing, reducing, neutral or in a vacuum. For example, the stainless-steel 304 sheath can be used in any type of environment with a maximum operating temperature of 890 °C.

MATERIAL OF THE SHEATH WITH MINERAL INSULATION				
SHEATH	MELTING POINT IN °C	MAX. AIR TEMP. IN °C	TYPE OF ENVIRONMENT	MAX. CONTINUOUS TEMPERATURE
304 SS	1400°C	1048°C	O,R,N,V	895°C
310 SS	1400°C	1071°C	O,R,N,V	1145°C
316 SS	1250°C	960°C	O,R,N,V	930°C
321 SS	1415°C	815°C	O,R,N,V	871°C
347 SS	1425°C	915°C	O,R,N,V	871°C
Inconel	1398°C	1095°C	O,N,V (*)	1145°C
Copper	1082°C	315°C	O,R,N,V (**)	315°C
Aluminium	660°C	425°C	O,R,N,V	371°C
Platinum	1770°C	1648°C	O,N (*)	1648°C
Molybdenum	2620°C	535°C	V,N,R	2626°C
Tantalum	3004°C	400°C	V	2760°C
Titanium	1815°C	315°C	V,N	1090°C

O = Oxidizing R=Reducing. N = Neutral. V = Vacuum
(*) = Sensitive to sulphuric corrosion
(**) = Deteriorates quickly in oxidizing environments

4 - TECHNICAL SPECIFICATIONS OF THERMOCOUPLES

4-1 : THE DIFFERENT TYPES OF HOT JUNCTIONS:

The part where the hot junction is made is exposed to the temperature to be measured. There are three main types of assembly:

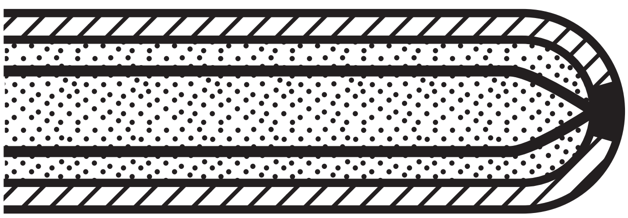
- Exposed hot junction
- Earthed hot junction
- Insulated hot junction

Exposed hot junction:

This type of junction provides a very quick response time. However, the thermocouple must be used in environments where the conditions are mild (neutral atmosphere, at atmospheric pressure, without any mechanical shocks or abrasions, etc.). In more severe conditions, the thermocouple may be designed for single use (in metallurgy for example).

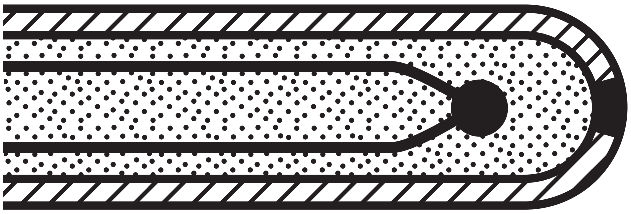
Earthed hot junction:

For this type of assembly, sheathed thermocouples are used. The hot junction is itself welded to the sheath to ensure a quick response time. In this way, the thermocouple is protected from the environmental conditions in which it is set up. With this production mode, thermocouples with small diameters may have a response time identical to or even better than the exposed junctions. Indeed, thanks to the sheath, the operational capability (better resistance to reducing or oxidizing atmospheres, for example) and the maximum temperature withstand are improved.



Insulated hot junction:

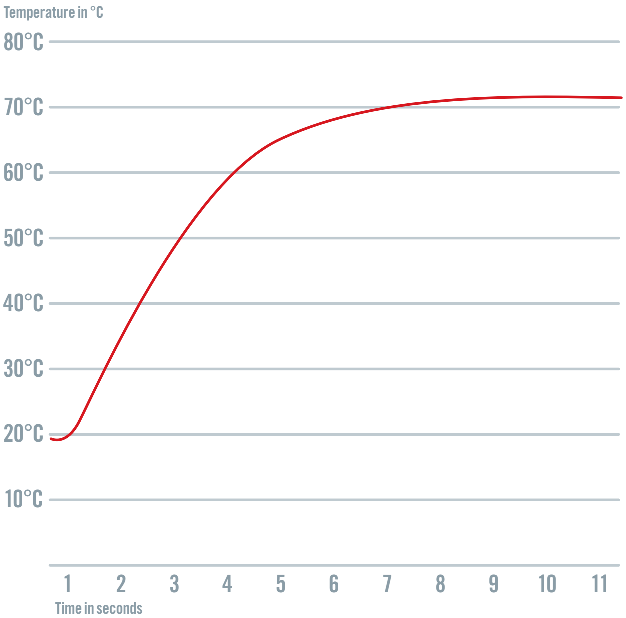
In this assembly, the hot junction and the sheath of the sheathed thermocouple are insulated by mineral insulation. This type of junction will be chosen if the thermocouple is used in an industrial environment. Indeed, without insulation, there may be electrical disturbances which interfere with the measurement. They may also damage or even destroy the instruments to which the sensors are connected. The drawback is a longer response time than the two previous types of assembly with an equivalent external diameter.



4-2 – RESPONSE TIME:

The value of the response time in seconds can be used to characterize the rapidity of the thermocouple's response after a thermal stress. This value represents the time necessary to reach 63% of the final value.

(below: graph showing a response time measurement)



Depending on the type of hot junction used, the characteristic response times which can be obtained are indicated below:

- Exposed: 0.1 seconds
- Earthed: 2.1 seconds
- Insulated: 4.5 seconds

The values in the table below are valid for thermocouples made with a sheathed cable and mineral insulation. They are given for information purposes.

DIAMETER	HOT JUNCTION	RESPONSE TIME (S)
0.5 mm	Insulated	0.3
0.5 mm	Earthed	0.05
1.0 mm	Insulated	0.4
1.0 mm	Earthed	0.1
3.0 mm	Insulated	1.5
3.0 mm	Earthed	0.7
4.5 mm	Insulated	2.0
4.5 mm	Earthed	1.1
6.0 mm	Insulated	4.0
6.0 mm	Earthed	2.1
6.0 mm	Exposed	0.1

Generally, the larger the diameter of the thermocouple, the longer the response time and the longer the life span of the sensor.

4-3 – REFERENCE STANDARD:

The IEC 584 standard and its French version NF EN 60584 cover thermo-electric couples

Part 1: Specifications and tolerances regarding emf

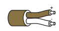
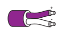
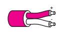
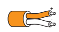
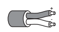
Part 3: Extension and compensation cables

Table of the correspondence between temperature and emf according to the type of thermocouple (extract from the NF EN 60584-1 standard):

TEMP.	TYPE OF THERMOCOUPLE							
	IEC 584							ASTM E988
	T	J	K	N	R	S	B	WRe 3 % -25 %
-40°C	-1.475	-1.960	-1.527	-1.023	-0.188	-0.194		
0°C	0	0	0	0	0	0	0	0
50°C	2.036	2.585	2.023	1.340	0.296	0.299	0.002	0.528
100°C	4.279	5.269	4.096	2.774	0.647	0.646	0.033	1.145
150°C	6.704	8.010	6.138	4.302	1.041	1.029	0.092	1.841
200°C	9.288	10.779	8.138	5.913	1.469	1.441	0.178	2.603
300°C	14.862	16.327	12.209	9.341	2.401	2.323	0.431	4.287
400°C	20.872	21.848	16.397	12.974	3.408	3.259	0.787	6.130
500°C		27.393	20.644	16.784	4.471	4.233	1.242	8.078
600°C		33.102	24.905	20.613	5.583	5.239	1.792	10.088
800°C			33.275	28.455	7.980	7.345	3.154	14.170
1000°C			41.276	36.256	10.506	9.587	4.834	18.230
1200°C			48.838	43.846	13.228	11.951	6.786	22.149
1400°C					16.040	14.373	8.956	25.882
1600°C					18.843	16.777	11.263	29.412
1800°C							13.591	32.712
2000°C								35.717

TYPE OF THERMOCOUPLE	TOLERANCE VALUES (±°C) AND TEMPERATURE LIMITS FOR VALIDITY		
	CLASS 1	CLASS 2	CLASS 3
Type T	0.5 or 0.004 x [t] -40°C to +350°C	1 or 0.0075 x [t] -40°C to +350°C	1 or 0.015 x [t] -200°C to +40°C
Type E Type J Type K Type N	1.5 or 0.004 x [t] -40°C to +800°C -40°C to +750°C -40°C to +1,000°C -40°C to +1,000°C	2.5 or 0.0075 x [t] -40°C to +900°C -40°C to +750°C -40°C to + 1,200°C -40°C to +1,200°C	2.5 or 0.015 x [t] -200°C to +40°C - -200°C to +40°C -200°C to +40°C
	1 for t < 1,100°C. [1 + 0.003 x (t= 1,100)] for t > 1,100°C	1.5 or 0.0025 x [t]	4 or 0.005 x [t]
Type R or S Type B	0°C to +1,600°C -	0°C to +1,600°C +600°C to +1,700°C	- - 600°C to +1,700°C
	-	0.01 x [t]	-
Type C Type A	- -	+426°C to +2.315°C +1,000°C to +2,500°C	- -

EXTENSION OR COMPENSATION CABLES

TC TYPE	EXTENSION CODE	COMPENSATION CODE	IEC 584-3 JULY 90
T	TX	TC	
J	JX	JC	
E	EX	EC	
K	KX	KC	
N	NX	NC	
R-S		KC / SCA	
B		BC	

5 -THERMOCOUPLE SELECTION CRITERIA FOR DEFINING A THERMOCOUPLE-BASED TEMPERATURE SENSOR

The thermocouples defined in the standard have different temperature ranges according to the atmosphere in which they are immersed. It is essential to know these parameters when choosing the type of thermocouple to use.

The table below indicates the theoretical temperature range for use of the thermocouples and the acceptable atmospheres:

TYPE OF THERMOCOUPLE	CODE	TEMPERATURE RANGE	ATMOSPHERE
Cu - CuNi	T	-20 °C / +350 °C	Moderately oxidizing or reducing
Fe - CuNi	J	-20 °C / +760 °C	Reducing, limited use in oxidizing atmospheres
NiCr - Ni alloy	K	-40 °C / +1100 °C	Oxidizing when clean or inert
Nicrosil - Nisil	N	0 °C / 1100 °C	Oxidizing when clean, limited use in reducing atmospheres
Pt - PtRh13%	R	0 °C / 1600 °C	Oxidizing
Pt - PtRh10%	S	0 °C / 1550 °C	Oxidizing
PtRh6 % - PtRh30%	B	100 °C / 1600 °C	Oxidizing
Tungsten W) Rhenium (Re)	C, A	0 °C / 2300 °C	Reducing, inert, hydrogen

5-1 BARE-WIRE THERMOCOUPLE

In many applications, type-K thermocouples can be used (temperature less than 1100°C).

We recommend the beaded types for platinum/rhodium thermocouples which can be used at higher temperatures.

For R, S and B thermocouples, we use a nominal wire size of 0.5 mm. The insulant used for this type of thermocouple is 99.7 %-pure alumina.

5-2 CHOOSING THERMOCOUPLES WITH MINERAL INSULATION

The behaviour of sheathed thermocouples is closely linked to their diameter in relation to the operating temperature.

Max. operating temperature for sheathed thermocouples:

TC	SHEATH		TEMP. MAXI. (°C)
	Ø (MM)	TYPE	
T	1	Stainless steel 304L	260
	1.5		260
	2		260
	3		315
	4.5		350
	6		350
	8		350
J	1	Stainless steel 304L	260
	1.5		440
	2		440
	3		520
	4.5		620
	6		720
	8		720
K	1	AISI 310	650
	1.5		650
	2		700
	3		750
	4.5		800
	6		800
	8		800
	1	AISI 446	700
	1.5		920
	2		920
	3		1070
	4.5		1100
	6		1100
	8		1100
	0.5	Inconel 600	600
	1		650
	1.5		650
	2		700
	3		750
	4.5		800
	6		1000
	8		1050
N	1.5	Inconel 600	650
	2		700
	3		750
	4.5		800
	6		1000
	3	Pyrosil	1070
	4.5		1150
	6		1150
	8		1150
S	1.5	Inconel 600	800
	2		800
	1.5	PtRh10%	1300

These max. operating temperatures are provided as an indication. The operating conditions (oxidizing or reducing atmosphere, thermal cycling, etc.) may alter these characteristics.

Particular attention should be paid to drift, which may be significant with thermocouples (pollution, metallurgical diffusion at the hot spot, etc.).

Periodic calibration may be appropriate or even necessary to detect this drift.

The table below shows the most widely-used thermocouples.

OUR STANDARD DIAMETERS FOR OUR MI CABLES (CABLES OF THERMOCOUPLES WITH MINERAL INSULATION)		
DIAMETER	TC TYPE	SHEATH
0.5 mm	K,N,J and T	Inconel 600 or SS 316
1.0 mm	K,N,J and T	Inconel 600 or SS 316
1.5 mm	K,N,J and T	Inconel 600 or SS 316
3.0 mm	K,N,J,R,S and T	Inconel 600 or SS 316
6.0 mm	K,N,J,R,S and T	Inconel 600 or SS 316

Notes: Other diameters and sheaths are available on request. For example: type-N thermocouples are available with several Nicrobel and/or Pyrosil sheaths.

C - RESISTANCE SENSORS

1 - TECHNICAL OVERVIEW

A resistance sensor, also called an RTD (Resistance Temperature Detector) works by taking advantage of the fact that the electrical resistance of certain metals increases or decreases when the temperature changes and these variations are reproducible and predictable.

RTD temperature ranges are smaller than those of some thermocouples and their response times are longer, but they are more stable and offer better repeatability over long periods of time.

Compared with thermocouples, they have the following advantages:

1. Large temperature range from -200 °C to +650 °C (theoretical, see below)
2. Characteristic quasi-linear curve
3. High accuracy
4. Good interchangeability

In industry, the most widely-used RTD is the Pt100 sensor. It is made of platinum (Pt) and has a resistance of 100 ohms at 0°C. Other variants also exist: Pt50, Pt200, Pt1000, as well as RTDs made of copper or nickel (used less and less frequently).

LAW OF RESISTANCE VARIATION/TEMPERATURE

The fundamental values of platinum measurement resistors in the 0 to 850°C and -200 to 0°C operating ranges are determined on the basis of the following interpolation functions (values based on ITS-90):

$R(t) = R_0 (1 + At + Bt^2)$ from 0°C to 850°C

$R(t) = R_0 [1 + At + Bt^2 + Ct^3 (t-100)]$ from -200°C to 0°C

$A = 3.9083 \times 10^{-3}$ °C^{-1}

$B = -5.775 \times 10^{-7}$ °C^{-2}

$C = -4.183 \times 10^{-12}$ °C^{-3}

Two different technologies are used:

- **resistors made of platinum wire wound on an insulating support.** In most cases, this support is ceramic, but glass supports are also used. The operating ranges extend up to 450 °C, and exceptionally up to 850 °C.

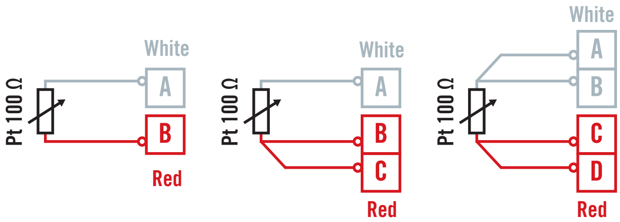
These sensing elements are used because of their high accuracy and stability.

- **platinum film deposited on a ceramic substrate.** The operating ranges extend up to 450 °C. They are less stable than traditional wound elements, but they offer excellent vibration withstand up to 200 °C, shorter response times and lower costs.

2 - MOUNTING OF A PT100 SENSOR

There are 3 possible ways of mounting a Pt100 probe in a sensor:

2-WIRE MOUNTING **3-WIRE MOUNTING** **4-WIRE MOUNTING**



These three mounting methods each have advantages and disadvantages.

- 2-wire mounting is the simplest and cheapest but it is also the least accurate. Indeed, the resistance of the connection cables is added to the sensor's resistance, leading to a significant error which increases with the length of the cable.

The resistance of the cables is:

R= Ro xL/s

where Ro is the resistivity of the cable (depends on the material used)

L : is the cable length

S : is the cross-section of the conductor

Copper has a resistivity of 17x10-9 ohms/metre.

If you use a copper cable with two conductors whose cross-section is $0.25 mm^2$ and whose length is 1 metre to hook up the Pt100, the resistance will be:

R = 17x10-9 x 1 / 0.25x10-6 = 0.068 ohm per conductor.

The total resistance will be 0.136 ohm.

As it is known that the resistance of a Pt100 varies by 0.3851 ohm/°C, 0.136 ohm represents an error of 0.35 °C!

- 3-wire mounting is the most widely-used method in industry because it offers the best compromise between cost and accuracy. Indeed, with this type of mounting, the cable's resistance is compensated by measuring the resistances of the loops A-B and B-C by means of a Wheatstone bridge. This implies that the three conductors have the same resistance. As this is never the case, there is still an error but it is minimal.

- 4-wire mounting is the most accurate because the line and contact resistance are eliminated by measurement (measurements between A-D and B-C). This solution is mainly used in the laboratory because it is more expensive to implement (addition of an extra conductor).

3 - STANDARD

The IEC 60751 international standard (Industrial platinum resistance thermometers and platinum temperature sensors) defines the specifications for the sensing elements and for temperature sensors, including:

- The relation between resistance and temperature
- the tolerances for the elements
- the tolerances for the sensors

IEC 751 CORRESPONDENCE TABLE (EXTRACTS): TEMPERATURE AND RESISTANCE

°C ITS 90	Ω	°C ITS 90	Ω	°C ITS 90	Ω	°C ITS 90	Ω	°C ITS 90	Ω
-200	18.52	10	103.9	210	179.53	410	250.53	610	316.92
-190	22.83	20	107.79	220	183.19	420	253.96	620	320.12
-180	27.10	30	111.67	230	186.84	430	257.38	630	323.30
-170	31.34	40	115.54	240	190.47	440	260.78	640	326.48
-160	35.54	50	119.4	250	194.10	450	264.18	650	329.64
-150	39.72	60	123.24	260	197.71	460	267.56	660	332.79
-140	43.88	70	127.08	270	201.31	470	270.93	670	335.93
-130	48.00	80	130.90	280	204.90	480	274.29	680	339.06
-120	52.11	90	134.71	290	208.48	490	277.64	690	342.18
-110	56.19	100	138.51	300	212.05	500	280.98	700	345.28
-100	60.26	110	142.29	310	215.61	510	284.30	710	348.38
-90	64.30	120	146.07	320	219.15	520	287.62	720	351.46
-80	68.33	130	149.83	330	222.68	530	290.92	730	354.53
-70	72.33	140	153.58	340	226.21	540	294.21	740	357.59
-60	76.33	150	157.33	350	229.72	550	297.49	750	360.64
-50	80.31	160	161.05	360	233.21	560	300.75	760	363.67
-40	84.27	170	164.77	370	236.70	570	304.01	770	366.70
-30	88.22	180	168.48	380	240.18	580	307.25	780	369.71
-20	92.16	190	172.17	390	243.64	590	310.49	790	372.71
-10	96.09	200	175.86	400	247.09	600	313.71	800	375.70
0	100.00							810	378.68
								820	381.65
								830	384.60
								840	387.55
								850	390.48

SENSOR TOLERANCE CLASSES

The IEC 751 standard defines the interchangeability tolerances as follows:

TOLERANCE CLASS	TOLERANCE
A	0.15 + 0.002 x [t]
B	0.3 + 0.005 x [t]

[t] is the absolute temperature value in °C.

According to the standard, the temperature sensors must not be exposed to temperatures higher than 600°C.

Drawing on our experience, we limit our industrial Pt 100 sensors to 450 °C in Class A.

TOLERANCE CLASSES FOR PT100 SENSORS

TEMPERATURE (°C)	TOLERANCE			
	CLASS A		CLASS B	
	(+/-°C)	(+/-Ω)	(+/-°C)	(+/-Ω)
-200	0.55	0.24	1.30	0.56
-100	0.35	0.14	0.80	0.32
0	0.15	0.06	0.30	0.12
100	0.35	0.13	0.80	0.30
200	0.55	0.20	1.30	0.48
300	0.75	0.27	1.80	0.64
400	0.95	0.33	2.30	0.79
500	2.80		0.93	
600	3.30		1.06	

The standard offers the possibility of having tolerance classes defined on the basis of a fraction of Class B.

Class B/3: Tolerance: 0.01 + 0.0017 x t

D - THERMOWELLS

Thermowells and protective tubes are used to protect the measuring elements of the thermocouples (hot junctions) or Pt100 sensors against mechanical damage and corrosive or contaminating environments.

The various types of construction available help users to choose the right combination for their needs.

For example: cast-iron protective tubes are mainly used in installations using molten aluminium, magnesium or zinc. Ceramic tubes are used in sectors such as the steel, glass, cement and lime industries. Their main advantages are their resistance to high temperatures and thermal shocks, their chemical inertness, their good resistance to abrasion and their high dielectric strength.

Thermowells must do two main jobs: :

The first involves protecting the temperature sensors against corrosion or oxidization linked to the treatment and against mechanical stresses. Each of the aforementioned materials provides different levels of protection for different operating conditions. They also enable the sensors to be dismantled without halting production.

The second is to ensure safety on the installation by providing perfect tightness between the process and the exterior. This means they must be designed to withstand the sometimes severe conditions in terms of pressure, flow rate and viscosity of the medium in which they are immersed.

When Directive No. 2014/68/EU: PRESSURE EQUIPMENT is applicable on our customers' installations, we can provide elements ensuring compliance (see chapter D-2).

In the pages which follow, you will find a list of the different materials, accompanied by recommendations concerning their use. As a general rule, it is advisable to use elements with a high chrome content because of its resistance to oxidization and sulphur at high temperatures. The presence of aluminium (1-2 %) in the surface is also useful because of its high resistance: a protective film forms, made up of a mixture of chrome oxide and alumina.

D-1 : MATERIALS FOR THERMOWELL CONSTRUCTION

Many types of steels and nickel-based alloys are used to manufacture thermowells. No other material is capable of withstanding the required operating conditions.

It is important to use the right metal for this type of product. Obviously, the use of an unsuitable metal will lead to premature malfunction, while a metal exceeding the required specifications for a given installation will lead to pointless expenditure.

The main metals used to make thermowells are carbon steel, chromium molybdenum steel, stainless steels (304, 310, 316, 321, 347, 304L, 316L, 446) and nickel-based alloys (Inconel, Incoloy, Hastelloy).

- STAINLESS STEELS:

Metals in this group form an invisible film of chrome oxide which withstands oxidization and corrosive attack by chemicals and acids. To be effective, they must contain at least 14 % chrome. Stainless steels in the 300 series are termed "austenitic", while those in the 400 series are called "ferritic". Unlike ferritic steels, austenitic stainless steels do not become brittle at low temperatures.

SS 304 : This austenitic stainless steel is generally the most widely recommended. Like the other stainless steels in the 300 series, SS 304 steel is subject to "carbide precipitation" between 370 and 900 ºC. In other words, the chrome produces carbides when SS 304 steel is cooled slowly within this temperature range. The ultimate result is localized depletion of the chrome around the carbides, which may lead to intergranular corrosion by acids or other corrosive substances.. This effect is particularly visible at the level of the welds (leading to disintegration of the welds). The maximum air temperature which SS 304 steel can withstand in continuous operation is 900 ºC. Constant vigilance is necessary because the solidity of the metal falls significantly at high temperatures. SS 304 steel is very widely used for producing thermowells for low-temperature applications as most organic and inorganic chemicals have no effect on it.

SS 310 : Contains more chrome (25 %) and nickel (20 %) to improve its high temperature withstand. SS 310 steel is subject to carbide precipitation between 400 and 870 ºC. The maximum air temperature which SS 310 steel can withstand in continuous operation is 1,150 ºC. It is used for applications requiring a good high temperature withstand or in carburizing and reducing environments.

SS 316 : This austenitic stainless steel is used widely due to its great versatility. SS 316 steel contains 18 % chrome and 12 % nickel, but also contains 2-3 % molybdenum to improve its resistance to chlorides. SS 316 steel is subject to carbide precipitation between 400 and 870 ºC. The maximum air temperature which it can withstand is 900ºC. SS 316 steel is used when greater resistance to corrosion is required, particularly in the presence of chlorides.

304L and 316L : The low-carbon versions of SS 304 and SS 316. These alloys help to solve the problem of carbide precipitation due to their low carbon content (0.03 % instead of 0.08 % maximum).

3 - NICKEL-BASED ALLOYS:

A. Incoloy, Inconel, Monel

The nickel-based alloys Inconel and Incoloy are a very important group of alloys. They offer excellent resistance to corrosive attack by a large number of aggressive chemicals. Their oxidization withstand is also excellent at high temperatures and their high temperature withstand is good.

They usually contain 15 to 23 % chrome to create a protective film of oxide. Inconel contains 40 to 73 % nickel, while Incoloy contains 32 to 42 % and 30 to 36 % iron. Some classes contain a small amount of titanium or tantalum to improve their high temperature withstand and aluminium to strengthen the protection provided by the oxide film when it is subjected to high temperatures (a film composed of a mixture of chrome oxide and aluminium oxide).

Inconel 600 : High level of nickel (76%) and chrome (15.5%) to withstand oxidizing and reducing environments. This alloy is used in several high-temperature corrosive environments.

Inconel 601: High level of nickel (76%) and chrome (15.5%), plus 1.5% aluminium. Good high temperature withstand. I601 offers remarkable resistance to oxidization and good resistance against carburizing environments and environments containing sulphur.

Incoloy 800: 32.5 % nickel, 46.0 % iron and 21 % chrome. Resistant to oxidization and corrosion in many environments.

Incoloy 800H: 32.5 % nickel, 46.0 % iron and 21 % chrome. Withstands oxidization and carburization at high temperature. Resistant to sulphuric attack and corrosion in many environments.

Incoloy 800H : A special version of Incoloy 800 steel with a small controlled amount of carbon to improve its high temperature withstand.

Monel 400 : High level of nickel (76%) and chrome (15.5%). Monel ensures good corrosion resistance in saltwater. Not subject to fissuring due to corrosion by chlorides. Monel is used for heat exchangers and applications involving sulphuric acid.

B. Hastelloy

This type of nickel-based alloy is used for excellent resistance to corrosion in many aggressive environments due to their high molybdenum content.

Hastelloy B : 61 % nickel, 28 % molybdenum. Excellent resistance to corrosion caused by hydrochloric, sulphuric, phosphoric and acetic acid, as well as hydrogen chloride.

Hastelloy C : 54 % nickel, 16 % molybdenum, 15.5 % chrome and 4 % tungsten. Excellent resistance to corrosion in many chemical environments, including ferric acid and copper chloride, contaminated inorganic acids and wet chlorine gas. Withstands oxidization at 1,000 °C.

Hastelloy X : 47 % nickel, 9 % molybdenum, 22 % chrome, 0.5% tungsten. Good high temperature withstand and resistant to corrosion at 1,200 °C. Also offers good resistance to reducing environments.

4 – OTHER MATERIALS:

For many applications, the temperature is too high to perform measurements with standard stainless-steel materials or with thermowells manufactured with nickel-based alloys. The most widely-used stainless steels and nickel-based alloys melt below or at 1,400 °C and weaken or become less rigid before reaching 1,400 °C.

Other materials have to be used for this type of applications.

There are two types of metals with melting points significantly higher than stainless steels and nickel-based alloys: tantalum, which melts at 2,996°C and molybdenum, which melts at 2,610°C. The nature of these metals limits their use at high temperatures, however:

- they oxidize quickly (tantalum oxidizes above 276 °C and molybdenum oxidizes above 500 °C). This means they cannot be used to manufacture thermowells, except in strictly non-oxidizing environments.

- In addition, they are too expensive to be used to manufacture standard thermowells or protective tubes. These materials are only used in a few applications, such as sintering furnaces for the nuclear industry.

The solution is to use protective tubes made of non-metallic or ceramic materials. Many materials of this type are available which withstand high temperatures, each with its own capabilities: quartz, silicon carbide, boron nitride, mullite and alumina.

Although these materials withstand high temperature to different degrees, they also have their disadvantages. As they are almost entirely ceramic, they are extremely brittle and can easily be broken when subjected to mechanical shocks. Furthermore, most of these materials do not withstand thermal shocks very well. If the material is suddenly exposed to a flame on one side, it expands. As the other side is colder, the expansion is not uniform. If the thermal shock is sufficiently strong, the protective tube will end up fissuring. The lower the thermal expansion coefficient of these materials, the greater their resistance to thermal shocks, which means they will crack less easily.

Below, you will find a presentation of the aforementioned materials with a few examples of widespread applications.

Quartz :

Quartz, which is pure silica, has a very low thermal expansion coefficient. This means it is particularly resistant to fissuring due to thermal shock. It is also particularly chemically inert and withstands attack by many corrosive chemicals and molten metals. Unfortunately, the fact that quartz is an overmelted "glass" limits the possibilities for its use. It devitrifies at around 1,094 °C, so it cannot be used for installations operating above this temperature.

In addition, any surface contamination accelerates devitrification at high temperatures (devitrification means that the quartz recrystallizes and cannot be used above 1,094 °C).

Quartz is often used in metal-casting industries as a disposable protective tube for a thermocouple due to its excellent resistance to thermal shocks. The quartz tube is immersed in the molten metal to measure the casting temperature. Due to its excellent resistance to thermal shocks, molten quartz can withstand sudden changes in temperature, from the ambient temperature to the melting temperature.

Silicon carbide:

Silicon carbide is another mineral resistant to the corrosion caused by many aggressive environments, such as acid gases. Its low thermal expansion coefficient gives it excellent resistance to thermal shocks and good thermal conductivity. This material is manufactured by the Carborundum Company, part of the St-Gobain Group. There are two types of silicon carbide: Carbofrax A, with approximately 90 % silicon carbide and the rest mainly silica, and KT silicon carbide, with approximately 96 % silicon carbide.

Thermowells made of Carbofrax are much less expensive than those made of KT silicon carbide, but they are not gas-tight. Their high temperature withstand is excellent, however, extending up to 1.649 °C. When this type of sensor is suitable, an internal "sleeve" made of alumina helps to protect platinum-rhodium thermocouples against contamination. KT silicon carbide is used for special applications, when gas-tight thermocouples are necessary. Silicon carbide is often used in metallurgy due to its good resistance to thermal shocks and its high-temperature capabilities. It is used as a protective tube, inserted into a ladle to measure the melting temperature.

Boron nitride:

Boron nitride is a synthetic material manufactured by the Carborundum Company Groupe St-Gobain and which can be used in oxidizing environments up to approximately 1,094 °C or in reduction of inert environments up to approximately 2,760 °C. Its thermal expansion coefficient is very low, making it highly resistant to thermal shocks. It is not subject to the wettability of many molten metals. Its main advantage is that is can be machined with ordinary equipment and it has lubricant qualities similar to those of graphite. Recently, boron nitride has started being used for thermowells with a calibrated type-B thermocouple to measure the casting temperature of cupronickels.

Alumina and Mullite:

Alumina (aluminium oxide) and mullite (a composite of alumina and silica) have been used for many years for thermowells for chrome-alumel and platinum-rhodium thermocouples. They can be used at high temperatures: 1,900 °C for highly pure alumina and 1,700 °C for mullite. One of the problems of these two materials is that they are sensitive to thermal shocks. They may crack if they are exposed to sudden, localized, uneven temperature changes, whether during heating or cooling.

The thermal expansion coefficient of mullite is equal to approximately 2/3 of alumina's thermal expansion coefficient, making it proportionally more resistant to thermal shocks. Both these materials are gas-tight. Unlike mullite, alumina must be used for platinum-rhodium thermocouples with applications in all types of environments except oxidizing environments. Indeed, silicon may be reduced by mullite and it contaminates platinum-rhodium thermocouples, compromising their calibration.

Generally, alumina and mullite are used to make protective tubes for high-temperature applications, where the risk of thermal shock or mechanical damage is low. This type of protective tube is also widely used in the glass industry.

D-2 - DIRECTIVE N°2014/68/UE : PRESSURE EQUIPMENT

The European Pressure Equipment Directive (PED) specifies the requirements concerning pressure equipment for the distribution of pressure equipment inside the European economic area. The version currently in force is directive 2014/68/EU of the European Parliament and Council dated 15th May 2014 regarding harmonization of the legislation in the member states concerning the commercialization of pressure equipment.

After examining the datasheets from the Pressure Equipment Liaison Committee (CLAP) concerning Directive 2014/68/EU, PYROCONTROLE can inform you that:

- An isolated sensor does not meet the definition of a pressure accessory (Guideline number A-25 – CLAP number X029)
- If a sensor is considered to be a component incorporated in an item of equipment, the requirements must be checked but the marking is not applicable (Guideline number A-22 – CLAP number X027)

- The compliance assessment procedures and the essential safety requirements in PED 97/23/CE are applicable to the whole safety chain (Guideline number A-25 – CLAP number X029)

Consequently, CE marking cannot be placed on an isolated sensor (in the context of the Pressure Equipment Directive).

To fulfil the requirements, we are capable of supplying the following:

- design calculation note (ASME 19.3 or other reference frameworks)
- traceability of materials
- qualification of the welds
- qualification of the welders
- tests and inspections (penetrant tests, helium test, PMI, hydraulic test, etc.)

EXAMPLE OF SENSOR CONFIGURATION

CONFIGURATOR CODE

Parameters to be indicated when ordering

	MODEL	PROCESS CONNECTION	HEAD	TC	SHEATH TYPE	Ø SHEATH (mm)	LENGTH L (mm)	HOT JUNCTION	EN OPTION TRANSMITTER	EN OPTION TRANSMITTER SCALE	EN OPTION OPTIONS
	TCG	5	2	1J	CM	6	500	I	A	0-600°	2
Reference in table and diagram		1	2	3	4	5	6		7		
Possible choice		None: 5 With extension and G1/2" connector: 6 With G1/2" connector under head: 9	DAN : 2	1T 1J 1K 1N 2K 2J	316L : AC INCONEL600 : CM PYROSIL : DB	4,5 6 8	100 à 30000	Insulated: I (standard) Earthed: M	LC5334A-100 : A LC5331A-321 : B LC5335A-100 : C		IP65 : 1 Epoxy : 2 IP65 + epoxy : 3

DIAGRAM

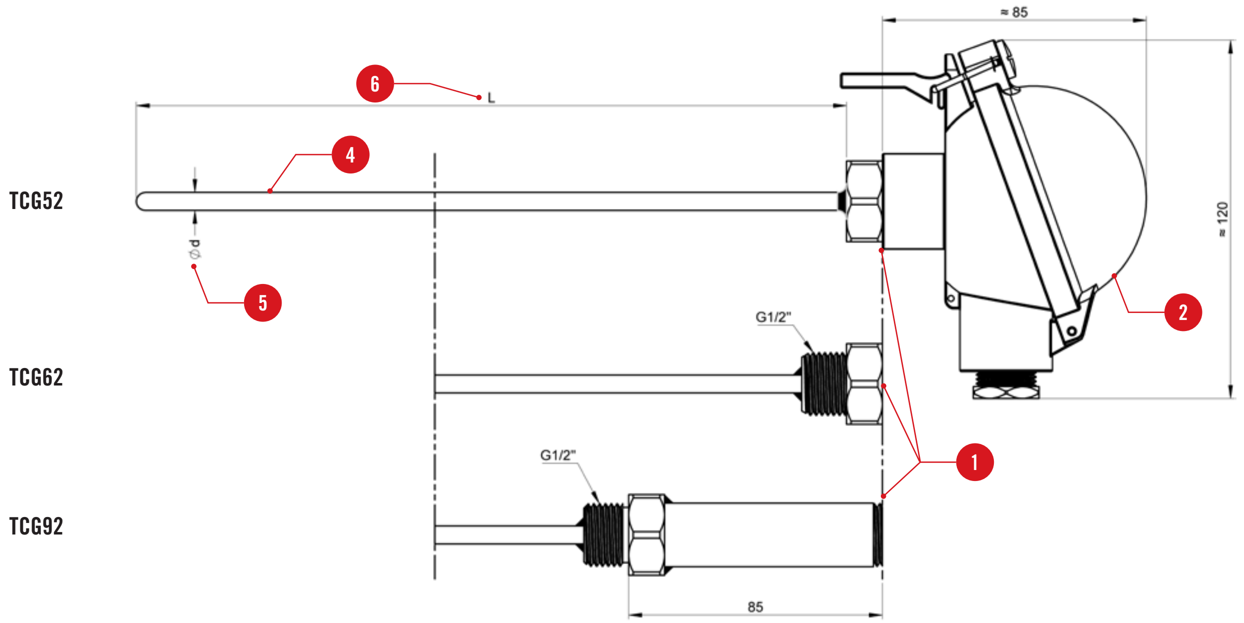


TABLE OF CONDUCTOR TYPE - WIRE DIAMETER

3 TC Class 1	Sheath diameter (mm)		
	4.5	6	8
T (class 2)	316L	316L	316L
J	316L	316L	316L
K	INCONEL600	INCONEL600	INCONEL600
N	INCONEL600	INCONEL600	-
	PYROSIL	PYROSIL	PYROSIL
2J	316L	316L	316L
2K	INCONEL600	INCONEL600	INCONEL600

4

TRANSMITTER (NOT COMPATIBLE FOR DUPLEX)

7

Transmitter			
Input	Output	Galvanic insulation	Reference
TC	4-20mA	1,5kV	LC5334A-100
TC + Pt100	4-20mA	1,5kV	LC5331A-321
TC + Pt100	4-20mA + HART	1,5kV	LC5335A-100

CONNECTION

Single thermocouple

Red +

Black -

Duplex thermocouple

Red +

Black -

Green +

-