A GUIDE TO

Temperature Measurement

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Temperature affects almost every process imaginable, yet it's difficult to measure accurately and reliably. Until now.

Given the variables surrounding temperature measurement, it is little surprise that accuracy and reliability have been a persistant problem.

As world leader, Cropico understand what it takes to reliably gain the most accurate and precise measurements possible.

Calibration laboratories and industries worldwide rely on our expertise and equipment. Great praise indeed.

This handbook offers an overview on the subject of 'Best temperature measurement practice,' explaining common causes of errors and how best to avoid them.

Also included are useful tables of wire and cable characteristics, temperature coefficients and various formula to ensure you make the best choice when selecting measurement equipment and measurement techniques.

We hope you find the booklet a valuable addition to your toolkit.

TEMPERATURE

Temperature can be defined as the amount of hotness or coldness of a body or environment. It can however, be more accurately described as molecular motion and energy flow, and can be measured in a number of ways i.e. the expansion of a liquid as seen in liquid in glass thermometers, or the change in resistance of a material such as copper or platinum.

Heat

Heat is internal energy that flows from a system at a higher temperature to a system at a lower temperature. Two bodies at the same temperature are said to be in thermal equilibrium. If a body at a higher temperature comes into contact with a body at lower temperature, heat will flow from the higher temperature to the lower one. If an ice cube is placed in a warm drink the heat from the drink will flow into the ice cube and melt it. The ice cube does not transfer its coldness to the drink, but of course the overall effect is for the drink to become slightly cooler.

TEMPERATURE SCALES

There are three temperature scales in common use today. They are Fahrenheit, Celsius, and Kelvin.

Fahrenheit

Daniel Gabriel Fahrenheit (1686-1736) was the German physicist who invented the alcohol thermometer in 1709 and the mercury thermometer in 1714. In 1724, he introduced the temperature scale that bears his name - Fahrenheit Scale. Fahrenheit temperature scale is a scale based on 32 for the freezing point of water and 212 for the boiling point of water. The interval between the two being divided into 180 parts.

Celsius

The Celsius temperature scale is also referred to as the "centigrade" scale. Centigrade means "consisting of or divided into 100 degrees". The Celsius scale, invented by Swedish Astronomer Anders Celsius (1701-1744), has 100 degrees between the freezing point (0 °C) and boiling point (100 °C) of pure water at sea level air pressure. The term "Celsius" was adopted in 1948 by an international conference on weights and measures.

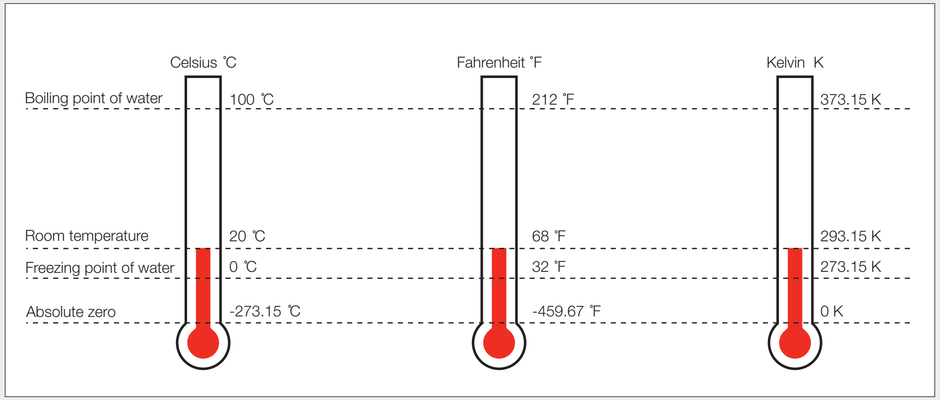
Celsius devised the centigrade scale or "Celsius scale" of temperature in 1742.

Until the 1970s the Fahrenheit temperature scale was in general common use in English-speaking countries; the Celsius, or centigrade, scale was employed in most other countries and for scientific purposes worldwide. Since that time, however, most English-speaking countries have officially adopted the Celsius scale

Kelvin

Kelvin temperature scale is the base unit of thermodynamic temperature measurement in the International System (SI) of measurement. It is defined as 1/ 273.16 of the triple point (equilibrium among the solid, liquid, and gaseous phases) of pure water. The kelvin (symbol K without the degree sign) is also the fundamental unit of the Kelvin scale, an absolute temperature scale named after the British physicist William Thomson, Baron Kelvin. Such a scale has as its zero point, absolute zero, the theoretical temperature at which the molecules of a substance have the lowest energy. Many physical laws and formulas can be expressed more simply when an absolute temperature scale is used; accordingly, the Kelvin scale has been adopted as the international standard for scientific temperature measurement. The Kelvin scale is related to the Celsius scale. The difference between the freezing and boiling points of water is 100 degrees in each, so that the Kelvin has the same magnitude as the degree Celsius.

Known Temperature				Required Temperature	Formulae
Celsius	°C	to	°F	Fahrenheit	°F = (1.8 X °C) + 32
Celsius	°C	to	K	Felvin	K = °C + 273.15
Fahrenheit	°F	to	°C	Celsius	°C = (°F - 32)/1.8
Fahrenheit	°F	to	K	Kelvin	K = °F + 459.67)/1.8
Kelvin	°K	to	°C	Celsius	°C = K-273.15
Kelvin	°K	to	°F	Fahrenheit	°F = (1.8 X K) - 459.67



THE INTERNATIONAL PRACTICAL TEMPERATURE SCALE

In 1990 the international practical temperature scale was revised with a very small shift in the definition of the scale reference point from the freezing point of water, as used in the previous 1968 scale, to the triple point of water. The triple point of water is the single combination of pressure and temperature at which pure water, pure ice, and pure water vapour can coexist in a stable equilibrium. This occurs at exactly 273.1598 K (0.0098 °C) and a pressure of 611.73 Pascals (ca. 6.1173 millibars, 0.0060373057 atm) a difference of 0.01°C in the 1990 scale ITS90.
With the introduction of the ITS90 scales the previously called “Degrees Kelvin” became Kelvin. The ITS90 scale has been adopted internationally and supersedes the previous International Practical Temperature Scale of 1968.

TEMPERATURE MEASUREMENT

Whilst temperature is one of the most common parameters measured it is also one of the most difficult to measure with any degree of accuracy. As explained above heat will always flow from the hot source to the less hot and try to find equilibrium. By inserting a probe to measure the temperature of a body you are immediately changing the body’s temperature. The amount of change in temperature caused by the temperature sensor will depend upon several factors;

- The relative masses of the probe and the source
- The difference in temperature between the probe and the source
- The amount of time allowed for the probe to assume the same temperature as the source.

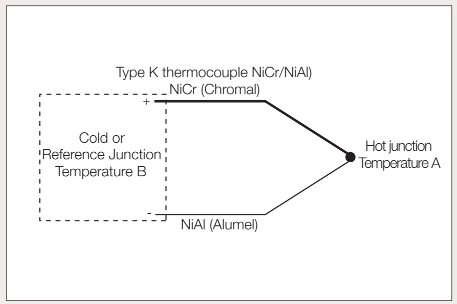
Not only is it difficult to measure temperature without the sensor intruding and changing the temperature, temperature is not a stable, static quantity. It is continually changing and trying to establish its thermal equilibrium. Consider, for example, trying to measure the air temperature in a room. There will be temperature differences and gradients across the room. The temperature near the door will be different to the temperature by the window, and it is important to understand this in the context of your measurements. It can become more important when measuring critical processes, for example a heat treatment oven in which metal components are tempered and hardened by the oven temperatures. The oven needs to be controlled to an even temperature over its whole interior. If there were cooler areas in the corners of the ovens, then some of the components treated may not have received the correct temperatures and be weakened as a result. For components that may be used in, for example, the manufacture of aircraft, this could be disastrous.
To achieve the best measurement results, the type and construction of the measurement sensor needs to be carefully selected. The mass should be kept to a minimum, the insertion depth of the probe should be sufficient so that any stem conduction does not interfere with the accurate measurement and the sensor should be left attached to the source for sufficient time to allow a state of thermal equilibrium between the source and the probe. Where large areas or components are to be measured it is often necessary to use several probes distributed around the area to be measured.
There are several sensor types available and the following sections (Thermocouples, Platinum Resistance temperature detectors (PRTD) and Thermistors (RTD)) will describe the main ones used for accurate temperature measurements.

Typical characteristics of the most common probe types

	Thermocouples	PRTD (Pt100)	Thermistor
Operating range	-200°C to +2000°C	-250°C to +850°C	-200 C to +2000°C
Accuracy (Typical)	Low 1°C	Very High 0.03°C	High 0.1°C
Linearity	Medium	High	Low
Thermal Response	Fast	Slow	Medium
Cost	Low	High	Medium
Long Term Stability	Low	High	Medium
Noise Problems	High	Medium	Low

THERMOCOUPLES

In 1822 an Estonian physician named Thomas Seebeck discovered that the junction between two metals generates a voltage that is a function of temperature. All thermocouples rely on this so-called Seebeck effect. Although in theory any two dissimilar metals when joined together will generate an emf, in practice when making thermocouples a small number of standard material types are used. Probably the most popular thermocouple is the type K (NiCr/NiAl). When the hot junction is heated a small voltage is generated in proportion to the difference in temperature between the heated junction and the cold or reference junction. This cold junction is usually the point at which the wires are connected to the voltmeter or measuring device.



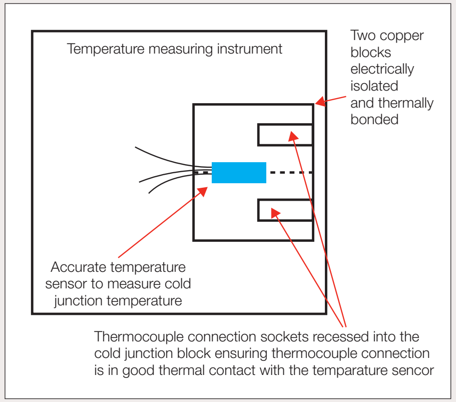
Because the voltage generated is proportional to the difference between the Hot and the Cold junctions, this does not represent the absolute temperature. To measure the absolute temperature we must also know the temperature of the Cold or Reference junction and add this to the difference temperature.

Absolute temperature = Temperature A + Temperature B

For an accurate absolute temperature measurement it is very important that the measuring indicator not only accurately measures the emf generated by the thermocouple but also accurately measures the cold junction temperature which is where the thermocouple is connected to the indicator. Most temperature indicators measure the thermocouple emf reasonably well, but are less able to measure the cold junction temperature with any degree of certainty.

Thermocouple Cold Junction (Reference Junction)

The importance of the cold junction or reference junction compensation when accurately measuring temperature cannot be stressed too highly, and will significantly affect the overall accuracy of absolute temperature measurement. Cropico thermometers are designed with the highest possible Cold junction measurement accuracy, ensuring that the absolute temperature is displayed with the highest degree of accuracy. For the best accuracy, the Cold junction reference point should be inside the instrument away from draughts and external temperature variations. The Reference point should also have a relatively high thermal mass, so any temperature changes are slowly and evenly spread across the Reference junction.



Incorporating a well constructed and accurate cold junction is of course costly and a lot of instrument manufacturers cut corners, and in doing so, increase the errors in the absolute temperature measurement displayed. Costs are cut in the following ways:

- Low cost terminals are used (sometimes not copper) instead of the recessed sockets in the copper block. If non-copper or nickel plated copper terminals are used, then additional thermocouple junctions are formed, which will generate emf. Connecting the thermocouple to terminals which are external to the instrument introduces errors due to non uniform temperatures being maintained. Draughts blowing across the terminals will produce temperature gradients. This effect can be minimised if the terminals are mounted on heat sinks with a large thermal mass.
- The sensor monitoring the cold junction temperature is of low cost and poor accuracy. Cropico use 4 wire platinum resistance sensors (Pt100) to ensure the best uncertainty of measurement.
- The cold junction sensor being poorly positioned. If external terminals are used then the sensor can only be placed nearby the terminals with no thermal bonding.

WARNING

When selecting your thermocouple measuring instrument, be sure to take into account the cold junction accuracy as well as the measuring accuracy. These are almost always stated separately and some manufacturers don't give a cold junction accuracy statement at all.

Thermocouple Measuring Instruments

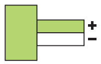
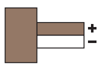
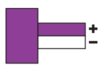
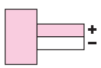
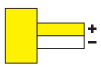
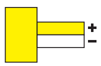
When choosing an instrument the accuracy statements should be read carefully and their implications understood. Thermocouples can have wide temperature ranges which make them very attractive for many applications, however, they are very non linear over the temperature range. For example: type K thermocouples can be used over the range -260°C to + 1370°C but the output varies from approximately 14µV/°C at -200°C to approximately 40µ/°C over the range 0...13700°C for the exact outputs, thermocouples tables need to be used see page 15 to 22. Measuring instruments have to be able to cope with this variation in voltage measurement, as well as being able to measure over the range -3.554mV (-100°C) to +41.865mV (+1000°C) with a degree of accuracy. The emf at 0°C is 0.0mV, so the measuring instrument has to be able to measure in the microvolt region accurately. The instrument stated temperature measuring uncertainty has to either be a catch-all statement (example: ±1°C) giving the poorest uncertainty of measurement achieved over the entire range, or the uncertainty measurement split into bands.
(Example: -200...-100°C ±1.0°C: -100...0°C ±0.8°C: 0...200°C ±0.2°C etc.) which gives a much better understanding of the achievable measurement uncertainty. Some manufacturers will state the measurement uncertainty in µV rather than temperature, and whilst this is the truest method of stating the uncertainty it makes it almost impossible to assess the thermometer's measurement performance without consulting the temperature tables and lengthy calculations.

Note: no mention has been made yet of the cold junction accuracy, and some thermometer specifications will not include it at all. Many specifications will include it in very small print, i.e. not obviously part of the main performance specification. The cold junction accuracy statement should give the uncertainty of its measurement at 20°C plus the additional errors for each degree away from 20°C and will look something like this: ±0.5°C at 20°C ±0.1°C per °C deviation. This means that at an ambient temperature of 20°C, the error

which must be added to the measurement uncertainty is ±0.5°C. If the ambient rises to 25°C then the error that must be added is ±[0.5°C + (5 x 0.1°C)] = 0.5 + 0.5 = ±1.0°C. So you can see for a measurement of 200°C the measurement uncertainty can increase five times if made at an ambient temperature of 25°C instead of 20 °C.
One final uncertainty that has to be added is the uncertainty of the thermocouples themselves, and the chart below gives the different types with their characteristics.

Thermocouples are good general purpose sensors, cheap to buy, capable of measuring over a very wide temperature range and can be small in size. There are a number of different thermocouple types available and the following table will assist in choosing the most appropriate type for your application.

Commonly Used Thermocouple Wire

ANSI Code	Alloy Combination		International IEC 584-3 Colour Coding	Temperature Range	Emf over temperature range	Limits of error* standard grade
	+ Lead	- Lead	Thermocouple			
J	Iron (magnetic) Fe	Constantan Copper Nickel Cu-Ni		0 to 750°C	-8.095mV to +69.553mV	2.2°C or 0.75%
K	Nickel-Chromium Ni-Cr	Nickel-Aluminium Ni-Al (magnetic)		-200 to +1250°C	-6.458mV to +54.886mV	2.2°C or 0.75% above 0°C 2.2°C or 2.0% below 0°C
T	Copper cu	Constantan Copper-Nickel Cu-Ni		-200 to +350°C	-6.528mV to +20.872mV	2.2°C or 0.75% above 0°C 1.0°C or 1.5% below 0°C
E	Chromel Nickel-Chromium Ni-Cr	Constantan Copper-Nickel Cu-Ni		-200 to +900°C	-9.835mV to 76.373mV	1.7°C or 0.5% above 0°C 1.7°C or 1.0% below 0°C
N	Nicrosil Ni-Cr-Si	Nisil Ni-Si-Mg		-270 to +1300°C	-4.345mV to 47.513mV	2.2°C or 0.75% above 0°C 2.2°C or 1.0% below 0°C
R	Platinum 13% Rhodium	Platinum Pt		0 to 1450°C	-0.226 to 21.101	1.5°C or 0.25%
S	Platinum 10% Rhodium Pt10%Rh	Platinum Pt		0 to 1450°C	-0.236 to 18.693	1.5°C or 0.25%
B	Platinum 30% Rhodium Pt30%Rh/Pt 6%Rh	Platinum 6% Rhodium Pt%5Rh	N/A	0 to 1700°C	0 to 13.820	0.5°C over 800°C

Type K - Chromel-Alumel.
The best known and dominant thermocouple belonging to the chromium-nickel aluminium group is type K. It is low cost and available in a wide variety of probe shapes and sizes. Its temperature range is extended (-200°C up to 1200°C range) depending on probe construction. Its emf /temperature curve is reasonably linear and its sensitivity is approximately 41 microvolt/ °C.

Type E - Chromel-Constantan
Due to its high sensitivity (68 microvolt/°C), Chromel-Constantan is mainly used in the cryogenic (low temperature) range (-200°C up to +900°C). The fact that it is non magnetic could be a further advantage in some special applications.

Type N - Nicros-Nisil
This thermocouple has very good thermoelectric stability, superior to other base metal thermocouples, and has excellent resistance to high temperature oxidation. The Nicrosil-Nisil thermocouple is ideally suited for accurate measurements in air up to 1200°C. In vacuum or controlled atmosphere, it can withstand temperatures in excess of 1200°C. Its sensitivity of 39 microvolts/°C at 900°C is slightly lower than type K (41 microvolts/°C). Interchangeability tolerances are the same as for type K. The type N thermocouple was designed to be an improved type K and is gaining in popularity.

Type J (Iron / Constantan)
Limited range (-40 to +750 °C) makes type J less popular than type K. The main application is with old equipment that cannot accept 'modern' thermocouples. J types should not be used above 760°C as an abrupt magnetic transformation will cause permanent decalibration. The sensitivity rises to 55microvlts/°C.

Type T - Copper-Constantan
This thermocouple is used less frequently. Its temperature range is limited to -200°C up to +350°C. It is, however, very useful in food, environmental and refrigeration applications. Tolerance class is superior to other base metal types and close tolerance versions are readily obtainable. The emf/temperature curve is quite nonlinear, especially around 0°C, and sensitivity is 42 microvolts/°C.
Thermocouple types B, R and S are all 'noble' metal thermocouples and exhibit similar characteristics. They are the most stable of all thermocouples, but due to their low sensitivity (approx 10 µV/°C), they are usually only used for high temperature measurement (>300 °C).

B - Platinum 30% Rhodium - Platinum 6% Rhodium
Type B allows measurements up to 1800°C. It is a very stable thermocouple but less sensitive in the lower range. Output is negligible at room temperature giving the same output at 0°C and 40°C thus making them unusable at low temperature. The revised temperature table for type B only states the accuracy for temperatures above 800°C. Historically these thermocouples

have been the basis of high temperature sensing in spite of their high cost and their low thermoelectric power. Until the launch of the Nicrosil-Nisil thermocouples, type N, they remained the sole option for good thermoelectric stability.

Type S - Platinum 10% Rhodium – Platinum
Suitable for high temperature measurements up to 1600°C, the low sensitivity (approx 10microvolts/°C) and high cost makes them unsuitable for general purpose use. They are normally used in oxidising atmosphere up to 1600°C. Their sensitivity is between 6 and 12 microvolts/°C.

Type R – Platinum 13% Rhodium – Platinum
Similar version to type S, suited for high temperature measurements up to 1600°C, but again with low sensitivity approx 10microvolts/°C making them unsuitable for general purpose use.

International Thermocouple Colour Codes

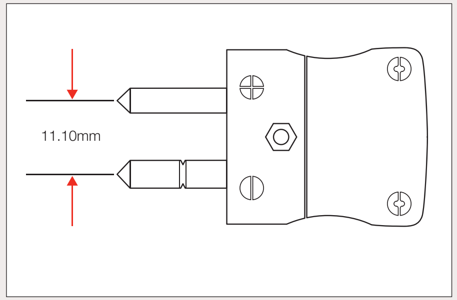
ANSI Code	Int. IEC 584-3 Colour Coding	British to BS 1843	German to DIN 43710	US Canadian ASTM E-230	Japanese to JIS C1610-1981	French to NFC 42-324
J						
K						
T						
E						
N			No Standard		No Standard	No Standard
R				No Standard		
S				No Standard		

Thermocouple Extension Cable
Thermocouples may be used to monitor the temperature of processes where it is necessary to have the temperature controllers or monitors a relatively long distance from the process. Thermocouples will operate over this long distance without additional errors, even if the temperature along the thermocouple cable run is not constant over its length, or is varying. Thermocouple extension wire has the same characteristics as thermocouple wire, but will usually have a lower temperature range than the thermocouple; this is due to its insulation material. The extension cable is designated with the letter X i.e. extension cable for type J thermocouple would be designated JX.

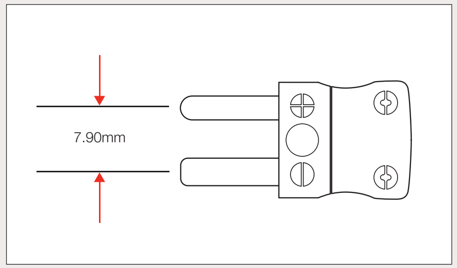
Thermocouple Compensating Cable
Thermocouple compensating cable has very similar characteristics to thermocouple cable over a relatively small temperature range based around the ambient temperatures. It is constructed of a different alloy to the thermocouple and designated with a C i.e. Compensating cable for type K thermocouple is designated KC.

Choosing a Thermocouple
Thermocouples are available either as bare wire 'bead' thermocouples which offer low cost and fast response times, or built into probes. A wide variety of probes are available, suitable for different measuring applications (industrial, scientific, food temperature, medical research etc). One word of warning: when selecting probes take care to ensure they have the correct type of connector. The two common types of connector are 'standard' with round pins and 'miniature' with flat pins; this causes some confusion as 'miniature' connectors are more popular than 'standard' types. When choosing a thermocouple, consideration should be given to the thermocouple type, insulation and probe construction. All of these will have an effect on the measurable temperature range, accuracy and reliability of the readings, listed.

Commonly Used Thermocouple Plugs



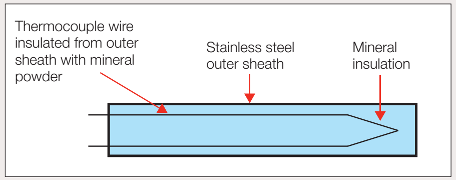
Standard thermocouple plug

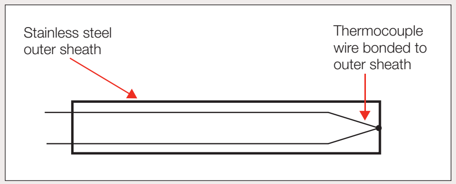


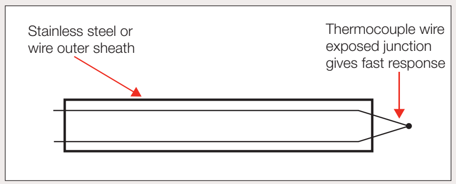
Miniature thermocouple plug

Common Thermocouple Construction

Thermocouples are usually constructed from thin wire which gives them a small thermal mass and correspondingly a quick reaction to temperature changes. They are constructed in many different configurations and shapes to suit the application but generally three basic construction types are used. The outer sheath can be stainless steel or Inconel which will withstand high temperatures and corrosive environments. Mineral insulation is often used to ensure high insulation resistance to the outer sheath. The exposed junction construction gives a fast response, but is more susceptible to physical damage or contamination by the process being measured.







Calibration of Thermocouples

Thermocouples and thermocouple wires are manufactured to give standards that specify the emf generated at specific temperatures. Thermocouple made from the same batch of wire will match each other much closer than the specified standard, but they may be on the edge of the standard's specification. To achieve greater degrees of measurement accuracy, it is beneficial to calibrate the thermocouples by measuring their emf at different temperature points. These temperatures would normally be selected as the critical temperatures of the process they were to monitor. Some measuring instruments have the ability to accept these calibration points and use them to achieve greater measurement accuracy.

Thermocouple calibration can also be compromised due to molecular contamination of the junction formed by the two wires; this can be due to temperature extremes annealing the wire or by cold working the wire, which can be caused by excessive handling, pulling through conduits or excessive vibration etc. This condition is potentially quite serious as the thermocouple appears to be operating correctly but is, in effect, giving measurement errors which can be quite high. Regular checking of the thermocouples and the measuring instrumentation is recommended.

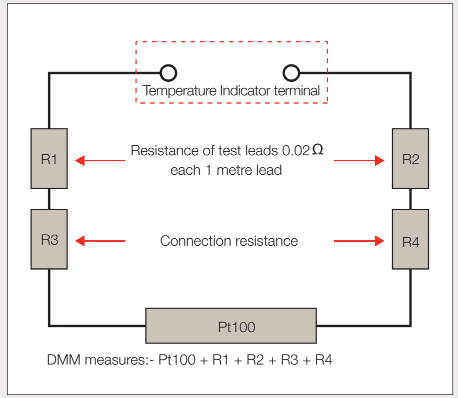
PLATINUM RESISTANCE THERMOMETERS

This type of measuring sensor is much more accurate than thermocouples but they have a more limited temperature range, a higher thermal mass and are more expensive. These resistance thermometers have a linear and repeatable resistance against temperature. The two common types in use are Pt100 which has a resistance of 100Ω at 0°C and Pt25 which has a resistance of 25Ω at 0°C. Platinum is used because it has a very stable temperature coefficient and, being a noble metal, is not very susceptible to contamination.

Pt100 (IPRT) is the most commonly used and has a temperature coefficient of ? = 0.00385 (European standard) which corresponds to an average resistance change, over the temperature range 0 to 100°C of 0.385Ω per °C. Both the absolute resistance value and the change in resistance per °C are both relatively small and give rise to measurement problems, especially when the resistance of the connection leads are taken into consideration.
There are other standards also in use The US standard for pt100 has an alpha of 0.00392.

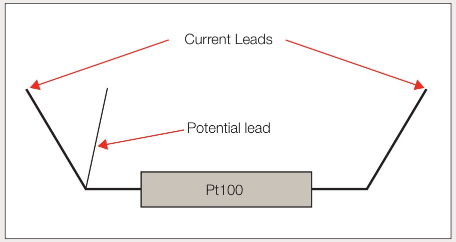
Two-Wire Measurements

When measuring the resistance of a Pt100 a test current is forced through the component and the test meter measures the voltage at its terminals. The meter then calculates and displays the resulting resistance and is known as a two-wire measurement. It should be noted that the meter measures the voltage at its terminals and not across the component. As a result of this, the voltage drop across the connection leads is also included in the resistance calculation. Good quality test leads will have a resistance of approximately 0.02 ohm per meter. In addition to the resistance of the leads, the resistance of the lead connection will also be included in the measurement and this can be as high as or even higher in value than the leads themselves. The two-wire measurement is not recommended.



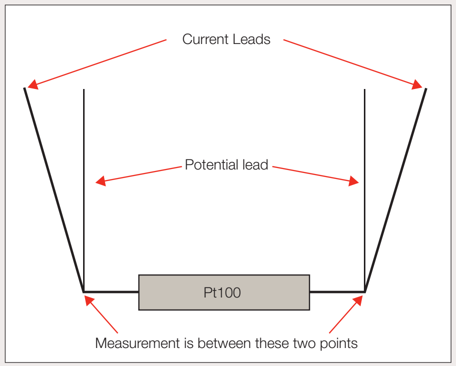
Three-Wire Measurement

A three-wire connection is quite common in industrial applications and will eliminate most of the effect of the lead resistance on the measured value. Care must be taken to ensure that all three wires are of equal resistance but this is almost impossible to achieve in practice. The three-wire method will not deliver the same degree of accuracy as a true four-wire system but is better than two wires.



Four-Wire Measurements

This is the most accurate measurement configuration. Two-wires are used to pass a constant current through the Pt100 and the volt drop across the unit is then measured. The impedance of the voltage measurement circuit is high and as a consequence only a very small current flows in the potential circuit, which for practical purposes can be ignored. The result is that the measurement lead resistance can also be ignored.



Two-wire sensors will also have large errors due to lead and connection resistance adding to the measured resistance value.

Three-wire sensors are better than two wires but will still give additional errors due to imbalance of lead resistances.

Four-wire sensors are recommended for accurate and repeatable measurements and the lead resistance can be ignored.

Measurement Errors

When measuring PRTs the measurement current used by most temperature indicators is either DC or low frequency AC. If AC is used, then care in selecting a non inductive sensor is essential as the measurement will be the impedance of the sensor rather than its true DC resistance. There may also be some differences in the temperature measurement between sensors from different manufacturers, as their construction technique may differ, resulting in slightly different impedance values. This AC measurement does, however, eliminate any thermal emf errors that may arise.

When DC current measurement is employed, the true resistance value is measured and used to calculate the corresponding temperature. In this instance impedance errors are not a problem, but errors due to thermal emf must be considered. The best method of countering any thermal emf is to measure the sensor resistances with current flowing in one direction, then reverse the current and taking a second measurement. The average of these two measurements is the true resistance without any thermal emf. This is often called the switched DC method and is selectable on the Cropico thermometers.

To obtain the best measurement results, the resistance of the Pt100 sensor must be measured with a high degree of accuracy. A temperature change of 1°C will correspond to a resistance change of 0.385Ω so to obtain a measuring accuracy of 0.01°C(10mK) the resistance must be measured to ±0.0385Ω. Example: for a temperature of 100°C the resistance value will be 138.5Ω. To measure this with an accuracy of ±0.01°C, this resistance value must be measured to ±0.0385Ω, which is equal to ±0.028%. If a current of 1mA is used as the measuring current to measure 138.5Ω (100°C), then a voltage of 138.5mV will need to be measured to ±138.5μV, and to measure the temperature change of 0.01°C, a change of 3.85μV must be measured. So you can see a small error in the voltage sensing measurement will give large temperature measurement errors. Cropico's long history of high accuracy low resistance measurement ensures that its range of thermometers offer the highest possible accuracy typically ±10mK.

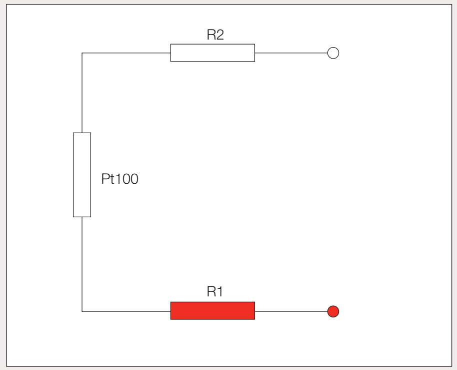
Self Heating

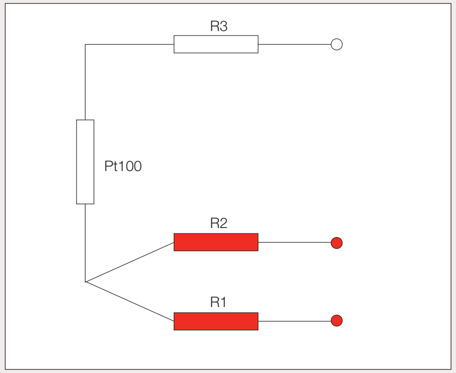
To measure the resistance of the temperature detector, a current must be passed through the device, typically a current 1mA to 5mA is used. A source current of 1mA flowing through the 100Ω resistance will generate 100μW of heat. If the sensor element is unable to dissipate this heat it will indicate an artificially high temperature. This effect can be minimised by using a large sensor element, by ensuring it is in good thermal contact with its measurement environment, and allowing sufficient time for the temperature to stabilise. An alternative is to use a short measurement pulse of current thus minimising the heating effect. The Cropico thermometers may be configured to measure with either a continuous or a short current pulse ensuring that the best possible measurement is made.

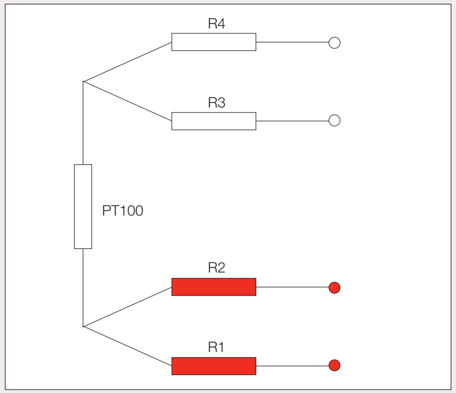
Colour Codes for Pt100

Two, three and four-wire extension leads as per IEC 60751

Note: In practice the industrial grade sensor will have current and potential leads R1,R2 and R3,R4 connected at the same point on the sensor and therefore interchangeable when connecting to the measuring device.







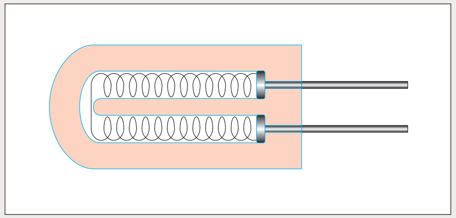
Stability

Whilst Platinum detectors are very stable over time, the design and manufacturing process can adversely affect these properties. During manufacture the detectors need to be heat treated to homogenize the crystal structure and remove any oxides that may have formed. The sensor needs to be supported in a stress-free manner and the finished assembly handled without causing any impact shocks or vibration.

Cycling the sensor between a high and low temperature will also increase errors. A typical drift rate for a Pt100 detector is 0.05°C per year. A high quality detector will exhibit lower drift of approx. 0.005°C to 0.01°C providing the detector is not mechanically stressed and the temperature range is limited. Consult the detector manufacturer for full specification.

Response Time

The Pt100 detectors are normally constructed by bifilar winding the platinum wire onto a small bobbin



Although the detector assemblies can be quite small in size they still have a thermal mass which takes time to warm up and reach thermal equilibrium, and consequently they have a longer response time than thermocouples. The detectors are usually housed in a stainless steel sheath which again increases the response time. When measuring temperatures, the immersion depth is also important as heat will be conducted up the stem of the sensor giving rise to errors. The manufacturer should be consulted regarding the minimum immersion depth.
Pt100 detector can also be constructed on a flat substrate this reduces the size and can be more suitable for some applications.

Table of Accuracies for Pt100 (a=0.00385)

Temperature (°C)	Tolerances					
	Class A IEC 60751 (1995)		Class B IEC 60751 (1995)		1/10 DIN DIN 43760	
	(±°C)	(± ohms)	(±°C)	(± ohms)	(±°C)	(± ohms)
-200	0,55	0,24	1,3	0,56	0.13	0.06
-100	0,35	0,14	0,8	0,32	0.08	0.03
0	0,15	0,06	0,3	0,12	0.03	0.01
100	0,35	0,13	0,8	0,30	0.08	0.03
200	0,55	0,20	1,3	0,48	0.13	0.05
300	0,75	0,27	1,8	0,64	-	-
400	0,95	0,33	2,3	0,79	-	-
500	1,15	0,38	2,8	0,93	-	-
600	1,35	0,43	3,3	1,06	-	-
650	1,45	0,46	3,6	1,13	-	-
700	-	-	3,8	1,17	-	-
800	-	-	4,3	1,28	-	-
850	-	-	4,6	1,34	-	-

Measurement Errors

The main sources of measurement errors are:-

- The use of two-wire sensors
- The use of three-wire sensors
- Thermal emf in non switch DC measurement systems
- Inductive sensors in AC measurement systems
- Self heating of the sensor due to the measurement current flowing through the detector winding
- Insufficient stabilisation time

The measurement errors can be minimised and eliminated by choosing one of the Cropico range of precision thermometers. The accuracy can be further improved by sensor calibration and the Callendar van Dusen coefficients produced from this calibration entered into the Cropico thermometer thus modifying the standard calibration curve to fit the detector characteristics. Whilst the platinum thermometer is one of the most linear temperature detectors it is still necessary to linearise the measured signal. According to the IEC standard IEC751 the non linearity can be expressed as

$$R_t = R^0[1 + At + Bt^2 + C(t - 100)t^3]$$

Where C is only applicable when t = ≤ 0°C. The standard coefficients for A, B, and C are stated in the IEC standard but may also be calculated for each individual sensor by measuring its resistance values against set temperature standards.

The Callendar van Dusen Method

Calendar van Dusen method for determining these coefficients is commonly used and based on measuring four known temperatures.

R_0 at T_0 = 0°C the triple point of water

R_{100} at t_{100} = 100°C The boiling point of water

R_h at t_h =high temperature (e.g. the freezing point of zinc 419.53°C)

R_1 at t_1 = a low temperature (e.g. the boiling point of oxygen -182.96°C)

The Callendar van Dusen coefficients will be calculated for you by the laboratory calibrating your sensor and so it is not necessary to describe the calculations here.

Pt25 SPRT

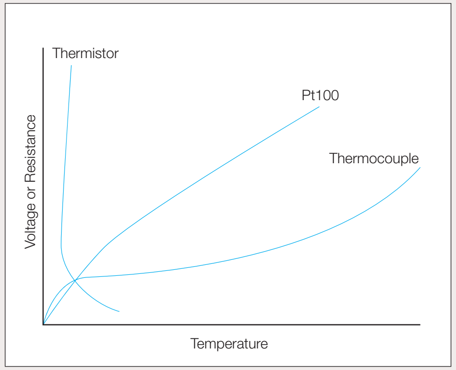
For the highest accuracy, special glass-sheathed standard PRTs, usually of 25 ohms at 0 °C, are calibrated at the fixed points of the International Temperature Scale 1990 (pg 24). ITS-90 specifies equations to relate the resistance to temperature and, using these, uncertainties can be achieved of 0.001 °C or better. Standard PRTs can be used from temperatures as low as -259 °C up to 660 °C, or even, 962 °C, with some increase in uncertainty and of loss of reproducibility.

The Cropico range of precision temperature indicators are able to measure with both Pt100 and Pt25 PRT sensors.

THERMISTORS

Thermistors are also a temperature sensitive resistance device and are more sensitive to temperature change than the thermocouple or Pt100. They are generally composed of semiconductor materials and are available with either positive temperature coefficient PTC (resistance increases with temperature) or negative temperature coefficient NTC (resistance decreases with temperature). The NTC types are the more commonly used and the resistance change per °C can be as large as several percent making them very good at detecting small changes in temperature, particularly when it is the change in temperature that we are interested in and not the absolute temperature value. NTC thermistors vary in their resistance values from a few ohms to 100kohms. This value is for a temperature at 25°C. The thermistor is a two-wire device but unlike PRTs the lead resistance is small in comparison with the detector resistance which is typically 1kΩ to 100kΩ and we, therefore, do not need to worry about the lead resistance introducing errors. As with PRTs we must ensure that the measuring current is kept low to avoid the effect of self heating.

Comparison of the different temperature detector types



Thermistor Terminology

Standard reference temperature is the thermistor body temperature at which nominal zero-power resistance is specified, usually 25°C.

Zero-power resistance is the DC resistance value of a thermistor measured at a specified temperature with a power dissipation by the thermistor low enough that any further decrease in power will result in not more than 0.1 percent (or 1/10 of the specified measurement tolerance, whichever is smaller) change in resistance.

Resistance ratio characteristic identifies the ratio of the zero-power resistance of a thermistor measured at 25°C to that resistance measured at 125°C.

Zero-power temperature coefficient of resistance is the ratio at a specified temperature (T), of the rate of change of zero-power resistance with temperature to the zero-power resistance of the thermistor.

NTC thermistor is one in which the zero-power resistance decreases with an increase in temperature.

PTC thermistor is one in which the zero-power resistance increases with an increase in temperature.

Maximum operating temperature is the maximum body temperature at which the thermistor will operate for an extended period of time with acceptable stability of its characteristics. This temperature is the result of internal or external heating, or both, and should not exceed the maximum value specified.

Maximum power rating of a thermistor is the maximum power which a thermistor will dissipate for an extended period of time with acceptable stability of its characteristics.

Dissipation constant is the ratio, (in milliwatts per °C) at a specified ambient temperature, of a change in power dissipation in a thermistor to the resultant body temperature change.

Thermal time constant of a thermistor is the time required for a thermistor to change 63.2 percent of the total difference between its initial and final body temperature when subjected to a step function

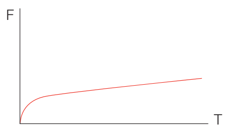
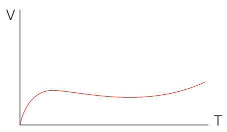
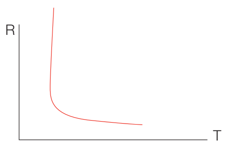
Resistance-temperature characteristic of a thermistor is the relationship between the zero-power resistance of a thermistor and its body temperature.

Temperature-wattage characteristic of a thermistor is the relationship at a specified ambient temperature between the thermistor temperature and the applied steady state wattage.

Current-time characteristic of a thermistor is the relationship at a specified ambient temperature between the current through a thermistor and time, upon application or interruption of voltage to it.

Stability of a thermistor is the ability of a thermistor to retain specified characteristics after being subjected to designated environmental or electrical test conditions.

Sensor Comparison chart

	RTD	Thermocouple	Thermistor
			
Temperature range	-260 to 850°C	-270 to 1800°C	-80 to 150°C (typical)
Sensor Cost	Moderate	Low	Low
System Cost	Moderate	High	Moderate
Stability	Best	Low	Moderate
Sensitivity	Moderate	Low	Best
Linearity	Best	Moderate	Poor
Specify for:	General purpose sensing Highest accuracy Temperature averaging	Highest temperatures	Best sensitivity Narrow ranges (e.g. medical) Point sensing
Advantages	Most Stable Most accurate More Linear than thermocouples	Self Powered Rugged Inexpensive Wide temperature range	High output Fast response
Disadvantages	Expensive Current source required Small ΔR Low absolute resistance	Non linear Low voltage Reference junction required Least stable & Least sensitive	Non linear Limited temperature range Current source required Self heating & Fragile

SI Unit Prefixes

Factor	Name	Symbol
10^{15}	peta	P
10^{12}	tera	T
10^{9}	Giga	G
10^{6}	Mega	M
10^{3}	Kilo	k
10^{2}	Hector	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	millo	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f