Temperature Hand Book

- Thermocouples
- RTDs
- Thermowells & Protection Tubes
- Glass Thermocouples
- Compensating Cables
- Instruments Cables
- Connection Heads & Accessories
- Calibration Equipments
- Calibration Services
- Industrial Heaters
- Non Contact Pyrometers
- Furnace Monitoring Cameras
- Industrial Furnaces

THERMAL °C ENGINEERING SOLUTIONS

TEMPSENS INSTRUMENTS

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About Us

Tempsens Instruments U# I

Tempsens Instruments U# II

AST & Marathon Plant

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TEMPSENS Instruments (I) Pvt. Ltd is a part of Pyrotech group which was established by four technocrats in 1976 at Udaipur, with its first product as Thermocouples and RTDs.

Today Tempsens is one of the largest manufacturer of temperature sensors with world class manufacturing facilities in India, Germany and China.

Tempsens is an ISO 9001:2008 certified company with NABL Accredited Laboratory.

The company is involved into manufacturing of Thermocouples, RTDs, Thermowells, Cables, Non contact Pyrometers, Heaters and Calibration Equipments etc. with Covered Area of 2,70 ,000 Sq. Ft.

Tempsens is proud of its technical solution, quick delivery, high technical standards and outstanding quality which have been appreciated and highly valued by its customers worldwide.

Tempsens exports to more than 50 countries.

Tempsens success is driven by its people and their unrelenting focus on delivering results the right way - by operating responsibly, executing with excellence, applying innovative technologies and capturing new opportunities for profitable growth.

Foreword

Dear friends,

We are pleased to bring to you the sixth edition of the temperature handbook, since the first handbook was published in 2006. We are happy with the response and demand of the handbook from industry. This handbook provides comprehensive technical details about temperature scale, sensors, calibration, etc. Reference tables and data about sensors have been provided in the Technical reference section. If you have any suggestion that can further improve the quality of content, please feel free to write us at: info@tempsens.com

Tempsens will celebrate its 40th anniversary in 2016. All these years, the company has been dedicated in the field of thermal engineering solution and cables. We are privileged, in fact blessed with the support by our esteemed clients.

We are ready to face more demanding applications in temperature sensing, heating and cables. Tempsens would actively pursue all possible demanding application for our scope of products in steel, cement, power, petrochemical, glass, semi-conductor, aerospace, laboratory etc.

We invite you to visit our facilities for first hand experience of our capabilities and potential. We know the only way to keep our business successful is to provide consistent, accurate and reliable products; and prompt services. We now have NABL accredited calibration labs in Udaipur, Bangalore and Baroda. We shall soon be in Germany; to be closer to you.

With these few words, we dedicate this publication to our valuable customers.

TEAM TEMPSENS

CONTENTS

1
Temperature and Temperature Scales

1.1 Temperature

The temperature of a substance is the degree of hotness or coldness of the substance. A hot substance is said to have a high temperature whereas a cold substance is said to have a low temperature. Therefore, the temperature of a substance is an indication of the average kinetic energy of the molecules of the substance. Heat always flow from a body at higher temperature to the body at lower temperature. So, we can also say that temperature of a body is the property which governs the flow of heat. It can easily be demonstrated as follows:

When two objects of the same material are placed together, the object with higher temperature cools while the cooler object gets warmer until a point is reached after which no more changes occurs.

1.1.1 Thermal Equilibrium

Heat energy flows from a body at higher temperature to another body at lower temperature. In other words, heat flows from a hotter to the colder body. The heat energy keeps flowing from the hotter to the cooler body until the temperature of both the bodies become equal. At this stage, the two bodies are said to be in thermal equilibrium. When two bodies attain the same temperature, they are said to be in thermal equilibrium with each other because then no heat flows from one body to another. The temperature thus reached is called as equilibrium temperature.

Therefore, now we can say that Temperature is that quantity which is same for both the system when they are in thermal equilibrium.

1.1.2 Zeroth Law of Thermodynamics

ZEROTH law of thermodynamics state that “If two systems are separately in thermal equilibrium with a third, then they must also be in thermal equilibrium with each other, and they all have the same temperature regardless of the kind of the system they are.”

This law can be restated as follows: If there are three or more than three systems which when taken together are in thermal contact and in thermal equilibrium as well, then any of the two system taken together are in equilibrium with one another.

1.2 Temperature Scale

One of the first attempts to make a standard temperature scale occurred in very past, when Galen, in his medical writings, proposed a standard "neutral" temperature made up of equal quantities of boiling water and ice; on either side of this temperature were four degrees of heat and four degrees of cold, respectively.

The earliest devices used to measure the temperature were called thermoscopes.

They consisted of a glass bulb having a long tube extending downward into a container of colored water, although Galileo in 1610 is supposed to have used wine. Some of the air in the bulb was expelled before placing it in the liquid, causing the liquid to rise into the tube. As the remaining air in the bulb was heated or cooled, the level of the liquid in the tube would vary reflecting the change in the air temperature.

An engraved scale on the tube allowed for a quantitative measure of the fluctuations.

The air in the bulb is referred to as the thermometric medium, i.e. the medium whose property changes with temperature.

In 1641, the first sealed thermometer that used liquid rather than air as the thermometric medium was developed for Ferdinand II, Grand Duke of Tuscany. His thermometer used a sealed alcohol-in-glass device, with 50 "degree" marks on its stem but no "fixed point" was used to zero the scale. These were referred to as "spirit" thermometers.

Robert Hook, Curator of the Royal Society, in 1664 used a red dye in the alcohol.

His scale, for which every degree represented an equal increment of volume equivalent to about 1/500 part of the volume of the thermometer liquid, needed only one fixed point. He selected the freezing point of water. By scaling it in this way, Hook showed that a standard scale could be established for thermometers of a variety of sizes. Hook's original thermometer became known as the standard of Gresham College and was used by the Royal Society until 1709. (The first intelligible meteorological records used this scale).

In 1702, the astronomer Ole Roemer of Copenhagen based his scale upon two fixed points: snow (or crushed ice) and the boiling point of water, and he recorded the daily temperatures at Copenhagen in 1708 - 1709 with this thermometer.

It was in 1724 that Gabriel Fahrenheit, an instrument maker of Däanzig and Amsterdam, used mercury as the thermometric liquid. Mercury's thermal expansion is large and fairly uniform, it does not stick to the glass, and it remains a liquid over a wide range of temperatures. Its silvery appearance makes it easy to read.

Fahrenheit described how he calibrated the scale of his mercury thermometer:

"Placing the thermometer in a mixture of salt ammoniac or sea salt, ice, and water a point on the scale will be found which is denoted as zero. A second point is obtained if the same mixture is used without salt. Denote this position as 30. A third point, designated as 96, is obtained if the thermometer is placed in the mouth so as to acquire the heat of a healthy man.”

On this scale, Fahrenheit measured the boiling point of water to be 212. Later he adjusted the freezing point of water to 32 so that the interval between the boiling and freezing points of water could be represented by the more rational number 180.

Temperatures measured on this scale are designated as degrees Fahrenheit (°F). In 1745, Carolus Linnaeus of Upsula, Sweden, described a scale in which the freezing point of water was zero, and the boiling point 100, making it a centigrade (one hundred steps) scale each step was called "degree". Anders Celsius (1701-1744) used the reverse scale in which 100 represented the freezing point and zero the boiling point of water, still, of course, with 100 degrees between the two fixed points.

In 1948 use of the Centigrade scale was dropped in favor of a new scale using degrees Celsius (°C).

(I) The triple point of water is defined to be 0.01° C.

(ii) A degree Celsius equals the same temperature change as a degree on the ideal-gas scale.

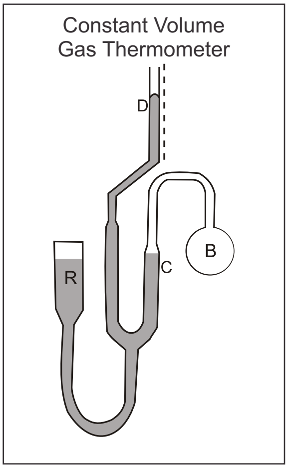
On the Celsius scale the boiling point of water at standard atmospheric pressure is 99.975 C in contrast to the 100 degrees defined by the Centigrade scale.

To convert from Celsius to Fahrenheit: multiply by 1.8 and add 32.

$° F = 1.8° C + 32$

$K = °C + 273.$

In 1780, J. A. C. Charles, a French physician, showed that for the same increase in temperature, all gases exhibited the same increase in volume. Because the expansion coefficient of gases is nearly the same, it is possible to establish a temperature scale based on a single fixed point rather than the two fixed- point scales, such as the Fahrenheit and Celsius scales. This brings us back to a thermometer that uses a gas as the thermometric medium.



In a constant volume gas thermometer a large bulb B of gas, hydrogen for example, under a set pressure connects with a mercury-filled "manometer" by means of a tube of very small volume. (The Bulb B is the temperature-sensing portion and should contain almost all of the hydrogen). Raising or lowering the mercury reservoir R may adjust the level of mercury at C. The pressure of the hydrogen gas, which is the "x" variable in the linear relation with temperature, is the difference between the levels D and C plus the pressure above D.P. Chappuis in 1887 conducted extensive studies of gas thermometers with constant pressure or with constant volume using hydrogen, nitrogen, and carbon dioxide as the thermometric medium. Based on his results, the Comité International des Poids et Measures adopted the constant-volume hydrogen scale based on fixed points at the ice point (0° C) and the steam point (100° C) as the practical scale for international meteorology.

Experiments with gas thermometers have shown that there is very little difference in the temperature scale for different gases. Thus, it is possible to set up a temperature scale that is independent of the thermometric medium if it is a gas at low pressure. In this case, all gases behave like an "Ideal Gas" and have a very simple relation between their pressure, volume, and temperature:

$pV= (\text{constant}) T.$

This temperature is called the thermodynamic temperature and is now accepted as the fundamental measure of temperature. Note that there is a naturally defined zero on this scale - it is the point at which the pressure of an ideal gas is zero, making the temperature also zero. With this as one point on the scale, only one other fixed point need be defined. In 1933, the International Committee of Weights and Measures adopted this fixed point as the triple point of water, the temperature at which water, ice, and water vapor coexist in equilibrium); its value is set as 273.16. The unit of temperature on this scale is called the Kelvin, after Lord Kelvin (William Thompson),

1824-1907, and its symbol is K (no degree symbol used).

To convert from Celsius to Kelvin, add 273

$\mathbf{K = ° C + 273}$

Thermodynamic temperature is the fundamental temperature; its unit is the Kelvin, which is defined as the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

Sir William Siemens, in 1871, proposed a thermometer whose thermometric medium is a metallic conductor whose resistance changes with temperature.

The element platinum does not oxidize at high temperatures and has a relatively uniform change in resistance with temperature over a large range. The Platinum Resistance.

Thermometer is now widely used as a thermoelectric thermometer and covers the temperature range from about -260° C to 1235°C.

1.2.1 Comparison of Different Temperature Scales

Scale Factor	°Celsius	°Reaumer	°Fahrenheit	Kelvin	°Rankine
Lower Fixed Point	0	0	32	273	491.67
Upper Fixed Point	100	80	212	373	671.67

Note: Celsius is denoted as C

Reaumer is denoted as Re

Fahrenheit is denoted as F

Kelvin is denoted as K

Rankine is denoted as Ra

1.2.2 Relationship Between Different Temperature Scales:

Sometimes it is required to change or convert the value of temperature from one temperature scale to another temperature scale, for this there is a requirement of relationship between different temperature scales. The relationship between different temperature scales is

(C-0 / 100) = (F-32/ 180) = (K-273/ 100) = (Re-0/ 80) = (Ra-491.67/ 180)

Where,

C, F, K, Re, Ra is denoting the different temperature scales.

0, 32, 273, 0, 491.67 is denoting the lower fixed points of different temperature scales & 100, 180, 100, 80, 180 is denoting the no. of divisions in different temperature scales.

For Example:

If you want to convert Celsius into Kelvin and if the value in Celsius is 37°C then we can find the value in Kelvin by applying the following formulae : **(C-0/ 100) = (K-273/100)**

1.3 International Temperature Scale

The first internationally recognized temperature scale was the international temperature scale of 1927 ITS-27. Its purpose was to define procedures by which specified, high quality yet practical thermometry could be calibrated such that the values of temperature obtained from them would be concise and consistent instrument-to-instrument and sensor-to-sensor, while simultaneously approximating to the appropriate thermodynamic values within the limits of the technology available.

This goal remains intact today.

ITS-27 extended from just below the boiling point of oxygen, -200°C, to beyond the freezing point of gold, 1065°C. Interpolation formulae were specified for platinum resistance thermometer calibrated at 0°C & at the boiling points of oxygen, water and sulphur (445°C). Above 660°C, the Pt-10% Rh vs. Pt thermocouple was specified for measurement. Above the gold point optical pyrometry was employed and the values of the fixed points were based on the best available gas thermometry data of the day.

ITS-27 was revised somewhat in 1948, and then more substantially in1968-with the adoption of the international practical temperature scale, IPTS-68. 1975 saw realignment with thermodynamic temperature through some numerical changes, and 1976 witnessed the introduction of the provisional 0.5 to 30Ktemperature scale EPT-76. The current scale, ITS-90, was adopted by the International Committee of Weights and Measures at its meeting in 1989, in accordance with the request embodied in Resolution 7 of the 18 General Conference of Weights and Measures of 1987. This scale supersedes the International Practical Temperature Scale of 1968 (amended edition of 1975) and the 1976 Provisional 0.5 K to 30 K Temperature Scale.

Essentially ITS 90 now defines a scale of temperature in five overlapping ranges.

Equalibirium State	t90/k	t90/°C
Triple point hydrogen	13.8033	-259.3467
Boilling point of hydrogen at pressure of 33321.3Pa	17.035	-256.115
Boilling point of hydrogen at pressure of 101292Pa	20.27	-252.88
Triple point of neon	24.5561	-248.5939
Triple point of oxygen	54.3584	-218.7916
Triple point of argon	83.8058	-189.3442
Triple point of mercury	234.3156	-38.8344
Triple point of water	273.16	0.01
Melting point of gallium	302.9146	29.7646
Freezing point of indium	429.7485	156.5985
Freezing point of tin	505.078	231.928
Freezing point of zinc	692.677	419.527
Freezing point of aluminium	933.473	660.323
Freezing point of silver	1234.93	961.78
Freezing point of gold	1337.33	1064.18
Freezing point of copper	1357.77	1084.62

These are: 0.65 to 5K using vapour pressures of Helium; 3 to 24.5561K via an interpolating constant volume gas thermometer; and 13.8033 to 273.16K (0.01°C) using ratioed resistances of qualified platinum resistance thermometers calibrated against various triple points. Then from 0 to 961.78° PRTs are again used calibrated at fixed freezing and melting points. Finally, above the freezing point of silver, the Planck law of radiation is used.

ITS-90 marked the culmination of a huge amount of effort (theoretical and practical) at National Physical Laboratory and elsewhere. It is not regarded as perfect, but is a close enough approximation to the real world of thermodynamic temperature. The goal of an International Temperature Scale is to provide an exact definition of a measurable and traceable continuum of the physical state we call the temperature.

2
Temperature Measurement

The measurement of temperature is very important in industrial application, so therefore continuous measurement of temperature is very much essential.

Temperature can be measured through various types of sensors; all of them run on the same basic principle that they give temperature in the output according to the changes produced in their physical characteristics in the input.

According to the type of application, measurement of temperature can be divided into following parts:

2.1 Contact Method

This method is used when the body (whose temperature is to be measured) and the sensor (which is measuring the temperature) can remain in contact with each other, in other words, we can say that if the body and the sensor can remain in contact with each other during the measurement of temperature than contact method is used.

Contact method uses three types of thermometers (temp. inst.)

1) Expansion Thermometers

2) Filled System Thermometers

3) Electrical temperature Instruments

2.1.1 Expansion Thermometers

In expansion thermometers bimetallic devices are used, in bimetallic devices there are two different materials whose rate of thermal expansion is also different. Therefore, in bimetallic devices there are strips of two metals which are bonded together. When heated, one side will expand more than the other, thus the resulting expansion is translated into temperature reading by a mechanical linkage to a pointer.

The advantage of this type of instrument is that they are portable and they do not need a power supply. And the disadvantages of this type of instrument are that they are not as accurate as other devices and can not be directly used for controlling or recording.

2.1.2 Filled System Thermometers

Filled system thermometer simply means that they are filled with any of the substitute. They generally come in two main classifications the mercury type and the organic-liquid type. Since, mercury is considered an environmental hazard, so there are regulations governing the shipment of that type of devices that contain it. Now a day, there are filled system thermometers which employ gas instead of liquids.

The advantages of these types of devices are that they do not require any electric power, they do not pose any explosion hazard and they are stable even after repeated cycling. And the disadvantage of these types of devices is that they do not generate data that are easily recorded or can be transmitted and they do not make spot or point measurements.

2.1.3 Electrical Temperature Instruments

As the name implies these types of instruments sense the temperature in the terms of electrical quantities like voltage, resistance etc. Therefore, we can say that these types of instruments are not directing indicating thermometers like mercury in glass devices.

In the majority of industrial and laboratory processes the measurement point is usually far from the indicating or controlling instrument. This may be due to necessity (e.g. an adverse environment) or convenience (e.g. centralized data acquisition).Therefore; Devices are required which convert temperature in to another form of signal, usually electrical quantities.

The most common devices used in these types of temperature instruments are

(a) thermocouples, (b) resistance thermometers and (c) thermistors, the similarity is, all of them require some form of contact with the body (of whose temperature is to be measured), the mode of contact could be immersed or it could be surface, depending on the construction of the sensor and the application where it is used.

2.1.3(a) Thermocouples

Thermocouples essentially comprises of a thermo element (which is a junction of two dissimilar metals) and an appropriate two wire extension lead. A thermocouple operates on the basis of the junction located in the process producing a small voltage, which increases with temperature. It does so on a reasonably stable and repeatable basis.

2.1.3(b) Resistance Thermometers

Resistance thermometer utilizes a precision resistor, the resistance (Ohms) value of which increases with temperature. RTD has had positive temperature coefficient. Such variations are very stable and precisely repeatable.

2.1.3(c) Thermistors

Thermistor is a semiconductor used as a temperature sensor. It is manufactured from a mixture of metal oxides pressed into a bead, wafer or other shape. The bead is heated under the pressure at high temperatures and then encapsulated with epoxy or glass. Beads can be very small, less than 1 mm in some cases.

The result of all these is a temperature sensing devices that displays a very distinct non linear resistance versus temperature relationship. The resistance of thermistor decreases with increase in the temperature; this is called as negative temperature coefficient of thermistor.

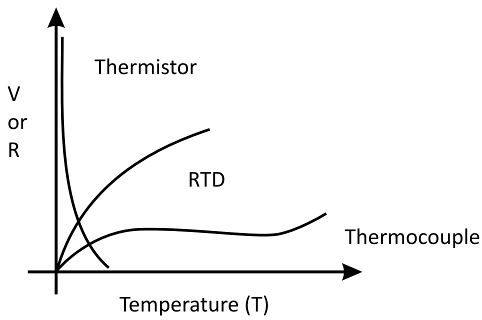
Thermistor exhibits a very large resistance changes for a small temperature change.

This can be as large as 3 to 5% per °C. This makes them very sensitive to small temperature changes. They can detect temperature change as low as 0.1°C or smaller. A thermistor element is significant smaller in size compared to RTDs.

The sensitivity of thermistors to temperature change and their small size make it ideal for use in medical equipment.

Disadvantage of Thermistors

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



Thermistors can be made very small which means they will respond quickly to temperature changes. It also means that their small thermal mass makes them especially susceptible to self-heating errors. Thermistors are good deal more fragile than RTD's or thermocouple and they must be carefully mounted to avoid crushing or bond separation.

2.2 Non-Contact Method

This method is used when the body (whose temperature is to be measured) and the sensor (which is measuring the temperature) are not allowed to remain in contact with each other, in other words, we can say that if the body and the sensor are not allowed to remain in contact with each other during the measurement of temperature then non contact method is used.

Most common thermometers (temperature instrument) using Non-Contact method are

a) Infrared sensors and Pyrometers

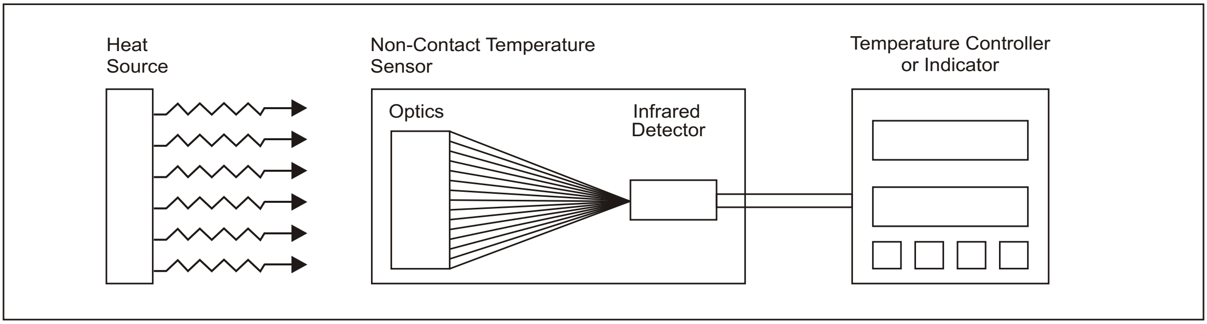
b) Thermal Imagers

2.2 (a) Infrared Sensors & Pyrometers

Infrared sensors & Pyrometer, now a day is the most common non contact temperature instrument in the industrial applications as it is easy to operate and use if the working principle is known to the user. Infra red sensor & Pyrometer measures the temperature of the object without being in the contact of the body but how is it possible? The answer is here, every object whose temperature is above absolute zero (-273.15K) emits radiation. This emission is heat radiation and its wavelength/frequency depends upon the temperature. So, this property of emission is used when the temperature is to be measured via non contact method.

The term infra red radiation is also in use because the wavelength of the majority of this radiation lies in the electromagnetic spectrum above the visible red light which is in the infra red region.

Similar to the radio broadcasting where emitted energy from a transmitter is captured by a receiver via an antenna and then transformed into sound waves, the emitted heat radiation of an object is received by detecting devices and transformed into electric signals, and in this way the temperature of an object is measured through non contact temperature measuring instruments.



2.3 Temperature Sensors Comparison Chart

Sensor	Advantages	Disadvantages
Thermocouple	Simple, rugged high temperature operation Low cost No resistance lead wire problems faster to temperature changes	Lease stable, least repeatable low sensitivity to small temperature changes. Extension wire must be of same T/C type wire may pick up radiated electrical noise if not shielded. Lowest accuracy Cold junction compensation
RTD	More stable over time more accurate Most repeatable temperature measurement Very resistant to contamination/corrosion of RTD element	High cost. Slowest response time. Low sensitivity to small temperature changes. Sensitivity to vibration(strains the platinum element wire) Decalibration if used beyond sensor's temperature rating. Somewhat fragile
Thermistor	High sensitivity to small temperature changes Temperature measurement become more stable with use Copper or nickel extension wires can be used	Limited temperature range Fragile some initial accuracy "drift" Decalibration if used beyond the sensor's temperature rating. Lack of standards of replacement.
Infrared	No contact with the product required Response times as fast or faster than thermocouples No corrosion or oxidation to affect sensor accuracy Good stability over time High repeatability	High initial cost. More complex support electronics required. Emmisivity variations affect temperature measurement accuracy. Field of view and spot size may restrict sensor application. Measuring accuracy affected by dust, smoke background radiation.

3
Thermocouple Fundamental

3.1 Introduction

Thermocouples are pairs of dissimilar metal wires joined at one end, which generate a net thermoelectric voltage between the open pair according to the temperature difference between the ends.

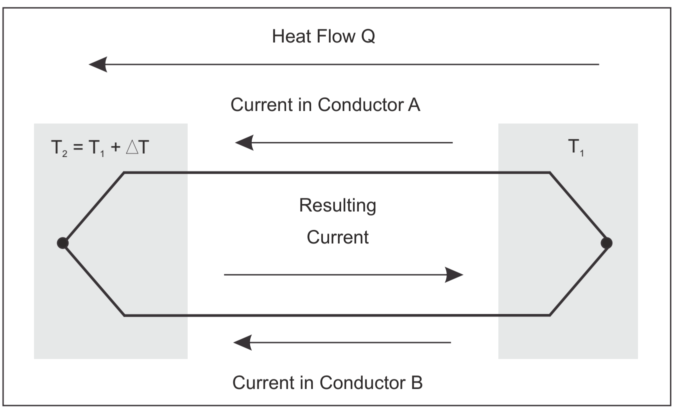
The junction that is put into the process in which temperature is being measured is called the HOT JUNCTION. The other junction which is at the last point of thermocouple material and which is almost always at some kind of measuring instrument is called the COLD JUNCTION.

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).

3.2 The Seebeck Effect

In 1821 a German physicist named Seebeck discovered the thermoelectric effect, which forms the basis of modern thermocouple technology. He observed that an electric current flows in a closed circuit of two dissimilar metals if their two junctions are at different temperatures. The thermoelectric voltage produced depends on the metals used and on the temperature relationship between the junctions. If the same temperature exists at the two junctions, the voltage produced at each junction cancel each other out and no current flows in the circuit. With different temperatures at each junction, different voltages are produced and current flows in the circuit. A Thermocouple can therefore only measure temperature differences between the two junctions.

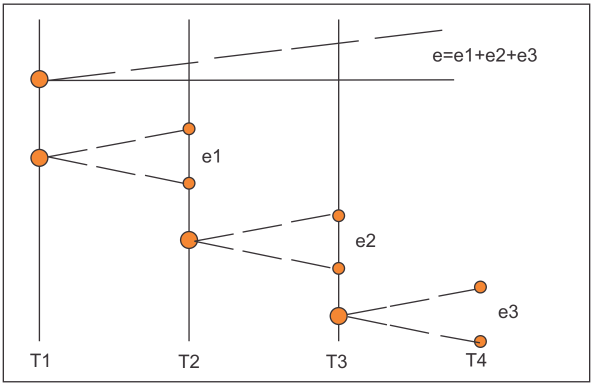
It is important to designate each of the junctions for practical purposes; the measuring junction (often referred to as the 'hot' junction) is that which is exposed to be measured temperature. The reference junction is the other junction that is kept at a known temperature; this is often referred to as the 'cold' junction. The term thermocouple refers to the complete system for producing thermal voltages and generally implies an actual assembly (i.e. a sheathed device with extension leads or terminal blocks).



The two conductors and associated measuring junction constitute a thermo element and the individual conductors are identified as the positive or negative leg.

The change in material EMF with respect to a change in temperature is called the Seebeck coefficient or thermoelectric sensitivity. This coefficient is usually a nonlinear function of temperature.

Law of Successive Thermocouple



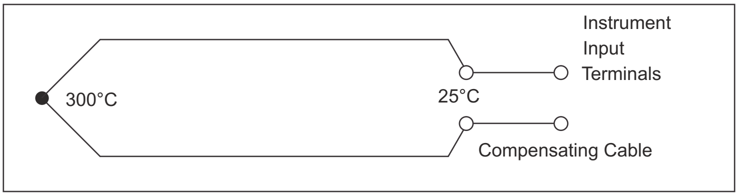
One thermocouple has its measuring point at T1 and open end at T2. The second thermocouple has its measuring point at T2 and its open end at T3. The third thermocouple has its measuring point at T3.The emf level for the thermocouple that is measuring T1 is e1; that for the other thermocouple is e2; and for the last thermocouple is e3. The sum of the three EMF's e1, e2, e3, equals the EMF 'e' that would be generated by the combined thermocouple operating between T1 & T4.

Hence a thermocouple is a sum of many thermocouples. For eg. An EMF produced by a thermocouple with hot junction at T1 & cold at T4; The EMF generated will be equal to many thermocouples joined together and produced EMF would be equals to sum of these three EMF e1, e2, e3.

$$e = e1+e2+e3$$

The characteristics of the thermocouple alloy should be uniform for the full length of thermocouple.

Note : Thermocouple is always formed when two metals are connected together. For example, when the Thermo element conductors are joined to copper cable or terminals, thermal voltages can be generated at the transition. In this case, the second junction can be taken as located at the connection point (assuming the two connections to be thermally common). The temperature of this connection point (terminal temperature) if known, allows computation of the temperature at the measuring junction. The thermal voltage resulting from the terminal temperature is added to the measured voltage and their sum corresponds to the thermal voltage against a 0°C reference.



If the measuring junction is at 300°C and the terminal temperature is 25°C, the measured thermal voltage for the type K thermo element (Nickel-Chromium v Nickel-Aluminum) is 11.18 mV. This corresponds to 275°C difference temperature. Therefore a positive correction of 25°C refers the temperature to 0°C reference; 300°C is thus indicated.

Important points to note at this stage are four-fold.

1. Thermocouples only generate an output in the regions where the temperature gradient exists- not beyond.

2. Accuracy and stability can only be assured if the thermoelectric characteristics of the thermocouple conductor s are uniform throughout.

3. Only a circuit comprising dissimilar materials in a temperature gradient generates an output.

4. Although the thermoelectric effects are seen at junctions, they are not due to any magic property of the junction itself.

3.3 Cold Junction Compensation

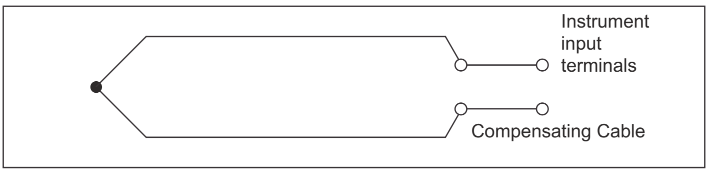
A practical industrial or laboratory Thermocouple consists of only a single (measuring) junction; the reference is always the terminal temperature.

Possible measures are:-

a) Measures the terminal temperature accurately and compensate accordingly in calculating the measured value.

b) Locate the terminals in a thermally controlled enclosure.

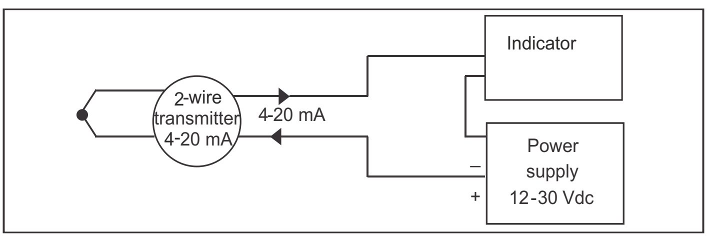
c) Terminate not in copper cable but use compensating or actual thermocouple wire to extend the sensor termination to the associated instrumentation (compensating cable uses low cost alloys, which have similar thermoelectric properties to the actual thermoelement). On this basis, there is no thermal voltage at the thermocouple termination. The transition to copper then occurs only at the instrument terminals where the ambient temperature can measure by the instrument; the reference junction can then be compensated for electronically.



Thermoelement with compensating cable

Note :- It is essential to use only compensating or specific extension cables (these have the correct thermoelectric properties) appropriate to the thermocouple other wise an additional thermocouple is formed at the connection point. The reference junction is formed where the compensating or extension cable is connected to a difference material. The cable used must not be extended with copper or with compensating cable of a different type.

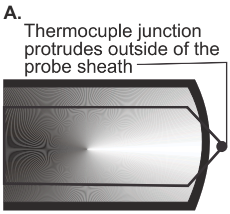
d) Use a temperature transmitter at the termination point. This is effectively bringing instrumentation close to the sensor where electronic reference junction techniques can be utilized. However, this technique is convenient and often used in plant; transmitter produces an amplified ''corrected' signal, which can be sent to remote instruments via copper cable of any length.



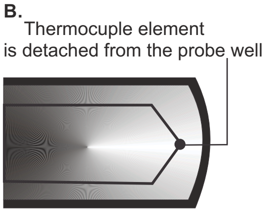
Temperature Transmitter 2- wire

3.4 Measuring Junctions

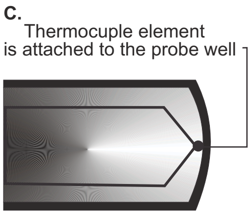
Three alternative tip configurations are usually offered:



a) **An exposed** (measuring) junction is recommended for the measurement of flowing or static non-corrosive gas temperature when the greatest sensitivity and quickest response is required.



b) **An insulated** junction is more suitable for corrosive media although the thermal response is slower. In some applications where more than one thermocouple connects to the associated instrumentation, insulation may be essential to avoid spurious signals occurring in the measuring circuits. If not specified, this is the standard.



c) **An earthed** (grounded) junction is also suitable for corrosive media and for high pressure applications. It provides faster response than the insulated junction and protection not offered by the exposed junction.

3.5 Method of Formation of Hot Junction

To form the hot junction, a suitable method has to be adopted to obtain a good electrical contact between the thermocouple wires.

For Chromal/Alumal and other combinations, for use in high temperature measurements, welding is the only method to obtain a suitable joint.

For this purpose Tig welding & Laser beam welding is mostly used.

Tig Welding

Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a nonconsumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by a shielding gas.

Laser Bbeam Welding

Laser beam welding (LBW) is a welding technique used to join multiple pieces of metal through the use of a laser. The beam provides a concentrated heat source, allowing for narrow, deep welds and high welding rates. LBW is a versatile process, capable of welding carbon steels, HSLA steels, stainless steel, aluminum and titanium. The speed of welding is proportional to the amount of power supplied but also depends on the type and thickness of the workpieces.

3.6 Thermocouple Standard

- ✓ ASTM E 235 : Standard Specification for Thermocouples, Sheathed, Type K and Type N for Nuclear or for other High-Reliability Applications.

- ✓ ASTM E 839 : Standard Test Methods for Sheathed Thermocouples and Sheathed Thermocouple Materials.
- ✓ ASTM E 220 : Test Methods for Calibration of Thermocouples by Comparison Techniques
- ✓ ASTM E 230 : Specification and Temperature-EMF Tables for Standardized Thermocouples.
- ✓ ASTM E 585 : Standard specification for compacted MI, MS, base metal thermocouple cables.
- ✓ ASTM E 608 : Standard specification for compacted MI, MS, base metal thermocouples.
- ✓ ASTM E 696 : Standard specifications for tungsten - rhenium alloy thermocouple wire.
- ✓ ASTM E 1652 : Standard specification for Magnesium oxide & Alumina oxide powder & crushable insulators used in metal sheathed PRT's, base metal thermocouples & noble metal thermocouple.
- ✓ IS 12579 : Specification for Base Metal Mineral Insulated Thermocouple Cables and Thermocouples.
- ✓ GB/T 1598 - 2010 : Chinese standard for platinum thermocouples.
- ✓ IEC 584 : International standard for thermocouples.

3.7 Types of Thermocouple

Many combinations of materials have been used to produce acceptable thermocouples, each with its own particular application spectrum. However, the value of interchangeability and the economics of mass production have led to standardization, with a few specific types now being easily available, and covering by far the majority of the temperature and environmental applications.

These thermocouples are made to conform to an e.m.f/ temperature relationship specified in the form of tabulated values of e.m.fs resolved normally to 1mV against temperature in 1C intervals, and vice versa. Internationally, these reference tables are published as IEC 584 1, 2 & 4, which is based on the International Temperature Scale ITS-90. It is worth noting here, however, that the standards do not address the construction or insulation of the cables themselves or other performance criteria. With the diversity to be found, manufacturers' own standards must be relied upon in this respect.

The standard covers the eight specified and most commonly used thermocouples, referring to their internationally recognized alpha character type designation & providing the full reference tables for each. These thermocouple types can be subdivided in 3 groups, base metal, noble (rare) metal & Refractory metal thermocouple.

3.7.1 Base Metal Thermocouples

Base metal thermocouple types are composed of common, inexpensive metals such as nickel, iron and copper. The thermocouple types E, J, K, N and T are among this group and are the most commonly used type of thermocouple.

Each leg of these different thermocouples is composed of a special alloy, which is usually referred to by their common names.

Type E – The type E thermocouple is composed of a positive leg of chromel (90%nickel/10%chromium) and a negative leg of constantan (45%nickel/55% copper). The temperature range for this thermocouple is -200 to 900°C (-330 to 1600^{0}F). The type E thermocouple has the highest millivolt (EMF) output of all established thermocouple types. Type E sensors can be used in sub-zero, oxidizing or inert applications but should not be used in sulphurous, vacuum or low oxygen atmospheres.

Type J – Type J thermocouples have an iron positive leg and a constantan negative leg. Type J thermocouples have a useful temperature range of 0 to 750°C (32 to 1400 °F) and can be used in vacuum, oxidizing, reducing and inert atmospheres. Due to the oxidation (rusting) problems associated with the iron leg, care must be takin when choosing this type for use in oxidizing environments above 537 °C.

Type K – The type K thermocouple has a Chromel (90% nickel/10% copper) positive leg and an Alumel (95%nickel/ 5% manganese, aluminum and silicon) negative leg. The temperature range for type K alloys is -200 to 1250°C (-328 to 2282°F). Type K sensors are recommended for use in oxidizing or completely inert environments. Type K and type E should not be used in sulfurous environments. Because type K has better oxidation resistance then types E, J and T, its main area of usage is at temperatures above 600°C but vacuum and low oxygen conditions should be avoided.

Type N – Type N thermocouples are made with a Nicrosil (74.1%nickel – 14.4% chromium – 1.4 % silicon.0.1%magnesium) positive leg and a Nisil (95.6% nickel to 4.4% silicon) negative leg. The temperature range for Type N is -270 to 1300°C (-450 to 2372°F). Type N is very similar to Type K except that it is less susceptible to selective oxidation. Type N should not be used in vacuum and or reducing environments in an unsheathed design.

Type T – Type T thermocouples are made with a copper positive leg and a constantan negative leg. The temperature range for type T is -200 to 350°C (-328 to 662°F). Type T sensors can be used in oxidizing (below 350°C), reducing or inert applications.

3.7.2 Noble Metal Thermocouples

Noble metal thermocouples are manufactured with wire that is made with precious or "noble" metals like Platinum and Rhodium. Noble metal thermocouples can used in oxidizing or inert applications and must be used with a ceramic protection tube surrounding the thermocouple element. These sensors are usually fragile and must not be used in applications that are reducing or in applications that contain metallic vapors.

Type R – Type R thermocouples are made with a platinum/13% rhodium positive leg and a pure platinum negative leg. The temperature range for type R is 0 to 1450°C (32 to 2642°F)

Type S – Type S thermocouples are made with a platinum/10% rhodium positive leg and a pure platinum negative leg. The temperature range for type S is 0 to 1450°C (32 to 2642°F)

Type B – Type B thermocouples are made with a platinum/30% rhodium positive leg and a platinum/6% Rhodium negative leg. The temperature range for type B is 0 to 1700°C (32 to 3092°F)

3.7.3 Refractory Metal Thermocouples

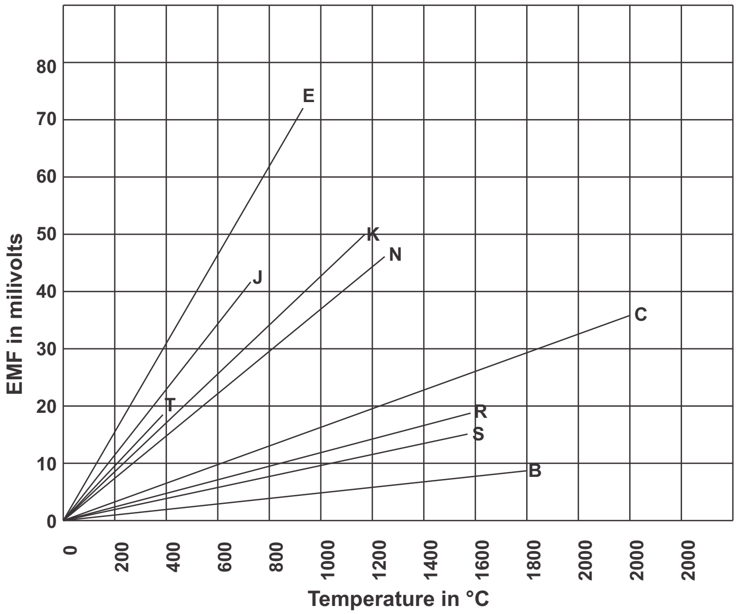
Refractory metal thermocouples are manufactured with wire that is made from the exotic metals tungsten and Rhenium. These metals are expensive, difficult to manufacture and wire made with these metals are very brittle. These thermocouples are intended to be used in vacuum furnaces at extremely high temperatures and must never be used in the presence of oxygen at temperatures above 300°C. There are several different combinations of alloys that have been used in the past but only one generally used at this time.

Type C- The type C thermocouple is made with a tungsten/5% rhenium positive leg and tungsten 26% rhenium negative leg and has a temperature range of 0 – 2320°C (32 – 4208°F).

Type G- Type G thermocouple technically also known as WM26Re. The type G thermocouple has alloy combination of tungsten (W) as positive lead and tungsten + 26% Rhenium (W-26% Re) as negative lead. Maximum useful temperature range of this thermocouple is 0 to 2320°C.

Type D- Type D thermocouple technically also known as W3ReM25Re. Type D thermocouple has alloy combination of tungsten + 3% rhenium (W-3%Re) as positive lead and tungsten + 25 % Rhenium (W-56% Re) as negative lead. Maximum useful temperature range of this thermocouple is 0 to 2320°C.

Thermocouple Type	Material + & -	Temperature Range(°C)	Application
E	Chromel & Constantan (Ni-Cr & Cu-Ni)	-200 to 900°C	Inert media, Oxidizing media
J	Iron & Constantan (Fe & Cu-Ni)	0 to 750°C	Inert media, Oxidizing media, Reducing media Vacuum
K	Chromel & Alumel (Ni-Cr & Ni-Al)	-200 to 1250°C	Inert media, Oxidizing media
N	Nicrosil & Nisil (Ni-Cr & Ni-Si)	-270 to 1300°C	Inert media, Oxidizing media
T	Copper & Constantan (Cu & Cu-Ni)	-200 to 350°C	Inert media, Oxidizing media, Reducing media Vacuum
R	87% Platinum/ 13% Rhodium & Platinum (Pt & Pt-Rh)	0 to 1450°C	Inert media, Oxidizing media,
S	90% Platinum/ 10% Rhodium & Platinum (Pt & Pt-Rh)	0 to 1450°C	Inert media, Oxidizing media,
B	70% Platinum/ 30% Rhodium & 94% Platinum/ 6% Rhodium (Pt-Rh & Pt-Rh)	0 to 1700°C	Inert media, Oxidizing media,
C	95% Tungsten/ 5% Rhenium & 74% Tungsten/ 26% Rhenium	0 to 2320°C	Vacuum inert and reducing
G	Tungsten & 74% Tungsten/ 26% Rhenium	0 to 2320°C	Vacuum inert and reducing
D	97% Tungsten 3% Rhenium & 75% Tungsten/ 25% Rhenium	0 to 2320°C	Vacuum inert and reducing



3.8 Types of Thermocouple Construction

There are two types of thermocouple construction is most commonly used.

Mineral Insulated (M.I.) Thermocouples & Non M.I. Thermocouples

3.8.1 Mineral Insulated Thermocouples

Magnesium Oxide insulated thermocouples, commonly referred as MgO thermocouples, are used in many process and laboratory applications. They are available in all thermocouple element types, a wide variety of sheath diameters and materials, they are rugged in nature and bendable, and their fairly high temperature ratings make MgO thermocouples a popular choice for a multitude of temperature measuring applications.

The many desirable characteristics make them a good choice for general and special purpose applications.

MgO sensors are constructed by placing an element or elements into a sheath of a suitable material and size, insulating the elements from themselves and the sheath with loose filled or crushable Magnesium Oxide powder or insulators, and then swaging or drawing the filled sheath down to its final reduced size. The swaging process produces an element with highly compacted MgO insulation and provides high dielectric strength insulation between the elements themselves and their sheath.

Mineral insulated Thermocouples consist of thermocouple wire embedded in a densely packed refractory oxide powder insulate all enclosed in a seamless, drawn metal sheath (usually stainless steel).

Effectively the thermoelement, insulation and sheath are combined as a flexible cable, which is available in different diameters, usually from 0.25mm to 10mm.

At one end cores and sheath are welded from a "hot " junction. At the other end, the thermocouple is connected to a "transition" of extension wires, connecting head or connector.

Advantages of mineral insulated thermocouple are

a) Small over all dimension and high flexibility, which enable temperature measurement in location with poor accessibility.

b) Good mechanical strength.

c) Protection of the thermo element wires against oxidation, corrosion and contamination.

d) Fast thermal response.

The mineral oxides used for insulation are highly hygroscopic and open-ended cables must be effectively sealed (usually with epoxy resins) to prevent moisture take-up. A carefully prepared mineral insulated thermocouple will normally have a high value of insulation resistance (many hundreds of mega ohms).

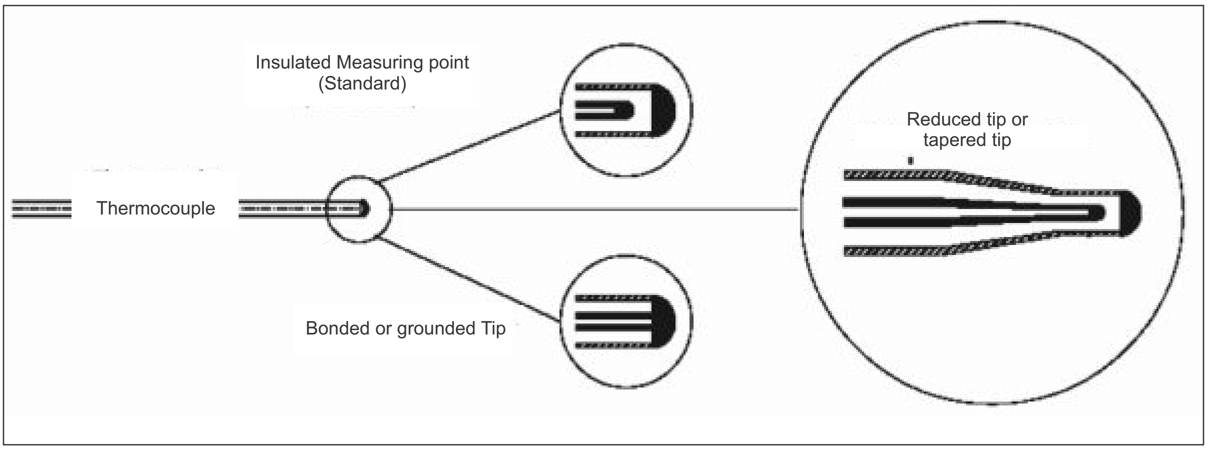
Mineral Insulated Thermocouple Tip Style

The junction tip of Mineral insulated thermocouple can be of three types as described previously. The tip can be insulated, grounded and reduced type.

a) Insulated Tip: Insulated hot end junctions are suitable for most applications, especially where low EMF pick-up is essential. High insulation resistance is enhanced due to extreme compaction of the high purity MgO powder insulation.

b) Bonded or grounded junctions offer a slightly faster temperature response than the insulated junction type. Not recommended for multi-point instrumentation.

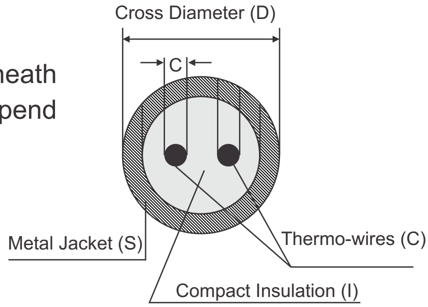
c) Reduced tip junctions are ideal for applications where low mass and extremely fast response times are required, together with good mechanical strength. Reduced tip can be provided on 1.0 to 6.0 mm diameter thermocouples.



Cross section view of M.I. Thermocouple

In above figure of M.I. thermocouple, S, I, C represent the terms sheath thickness, insulation, conductor respectively. These values depend upon the outer diameter (D) of M.I. thermocouple.

Number of Thermoelements	2	4	6
Minimum Sheath Thickness	10%	10%	10%
Minimum Thermoelement Diameter	15%	12%	9 %
Minimum Insulation Thickness	7%	5.5%	4%



Cross Section of Shell Lines

3.8.2 Non M.I. Thermocouples

In Non-M.I. thermocouples, thermocouple wires are either insulated with ceramic beads or after insulation of ceramic, covered by a metal sheath (usually stainless steel) and some form of termination (extension lead, connecting head or connector for example) is provided. In this type of construction thermocouple wires are protected from the measuring environment when a sheath protection is provided. The sheath material is dependent on the measuring environment usually stainless steel is used. According to the corrosive environment sheath selection is changed.

This construction does not provide flexibility & not found in small sizes. Not too good mechanical strength.

In Non M.I. construction sheath may be of ceramic or metal as per suitability.

Exposed, Grounded and Ungrounded all types of junctions are formed in both the M.I., & Non M.I. construction.

3.9. Characteristics of Thermocouple

3.9.1 Tolerances on Temperature Reading

Tolerance denotes the maximum allowable value obtained by subtracting the temperature reading or the temperature at the hot junction from the standard temperature converted from the applicable temperature EMF table.

Type of thermoco-uple	Tolerance Grade					
	ASTM E230-ANSI MC 96.1			IEC 584-2		
	Temperature range (°C)	Standard	Special	Temperature Range (°C)	Class 1	Class 2
B	800 to 1700°C	±0.5%	- - -	600 to 1700°C	±1°C or ±{(1+(T-1100) x .0.3%)}	±1.5°C or ±0.25%
R & S	0 to 1450°C	±0.5°C or ±0.25%	±0.6°C or ±0.1%	0 to 1600°C	±1°C or ±{(1+(T-1100) x .0.3%)}	±1.5°C or ±0.25%
N & K	-200 to 0°C	±2.2°C or ±2%	- - -	-40 to 1000°C	±1.5°C or ±0.4%	±2.5°C or ±0.75%
	0 to 1260°C	±2.2°C or ±0.75%	±1.1°C or ±0.4%			

Type of thermocouple	Tolerance Grade					
	ASTM E230-ANSI MC 96.1			IEC 584-2		
	Temperature range (°C)	Standard	Special	Temperature Range (°C)	Class 1	Class 2
E	-200 to 0°C	±1.7°C or ±1%	- - -	-40 to 800°C	±1.5°C or ±0.4%	±2.5°C or ±0.75%
	0 to 870°C	±1.7°C or ±0.5%	±1.0°C or ±0.4%			
J	0 to 760°C	±2.2°C or ±0.75%	±1.1°C or ±0.4%	-40 to 750°C	±1.5°C or ±0.4%	±2.5°C or ±0.75%
T	-200 to 0°C	±1.0°C or ±1.5%	- - -	-40 to 350°C	±0.5°C or ±0.4%	±1°C or ±0.75%
	0 to 370°C	±1.0°C or ±0.75%	±0.5°C or ±0.4%			
C	0 to 2320°C	4.5°C or ±1.0%	- - -	- - -	- - -	- - -

3.9.2 Maximum Operating Temperature

Operating temperature limit means the upper temperature where thermocouple can be used continuously in air. Maximum limit means the upper temperature where thermocouple can be used temporarily for short period of time owing to unavoidable circumstances. This graph is given as a guide only, and not to be guaranteed.

Principal factors that affect the life of a thermocouple are:

- **Temperature :** Thermocouple life decreases by about 50% when an increase of 50 °C occurs.
- **Diameter :** By doubling the diameter of the wire, the life increases by 2-3 times.
- **Thermic cycling :** When thermocouples are exposed to thermic cycling from room temperature to above 500°C, their life decreases by about 50% compared to a thermocouple used continuously at the same temperature.
- **Protection :** When thermocouples are covered by a protective sheath and placed into ceramic insulators, their life is considerably extended.

For bare wire thermocouple :

Type of Thermocouple	Upper temperature limit for various wire sizes				
	No. 8 AWG 3.25 mm (°C)	No. 14 AWG 1.63 mm (°C)	No. 20 AWG 0.81 mm (°C)	No. 24 AWG 0.51 mm (°C)	No. 28 AWG 0.33 mm (°C)
T	- - -	370	260	200	200
J	760	590	480	370	370
E	870	650	540	430	430
K	1260	1090	980	870	870
N	1260	1090	980	870	870
R, S	- - -	- - -	- - -	1480	- - -
B	- - -	- - -	- - -	1700	- - -

For Mineral Insulated Cables :

Type of Thermocouple	Upper temperature limit for various SS316 sheath diameters							
	0.5 mm (°C)	1.0 mm (°C)	1.5 mm (°C)	2.0 mm (°C)	3.0 mm (°C)	4.5 mm (°C)	6.0 mm (°C)	8.0 mm (°C)
T	260	260	260	315	370	370	370	370
J	260	260	440	440	520	620	720	720
E	300	300	510	510	650	730	820	820
K	700	700	920	920	1070	1150	1150	1150
N	700	700	920	920	1070	1150	1150	1150

While application conditions do alter techniques, the following factors are suggested for consideration.

1. Obtain thermocouples with insulated measuring junctions.
2. Specify “same metal” for large installation, preferably close tolerance.
3. Thermocouple reference junction should be monitored in a reference unit with an accuracy of +0.1°C or better.
4. Great care to be taken in running thermocouple circuitry against "Pickup" etc. with the minimum number of joints in the wiring.
5. Heat-treat thermocouple to their most stable condition.
6. Calibrate thermocouples.

3.9.3 Thermocouple Response Times

The response time for a thermocouple is usually defined as the time taken for the thermal voltage (output) to reach 63% of maximum for the step change temperature. It is dependent on several parameters including the thermocouple dimension, construction, tip configuration and the nature of the medium in which the sensor is located. If the thermocouple is plunged in to a medium with a high thermal capacity and heat transfer is rapid, the effective response time will be practically the same as for the thermocouple itself (the intrinsic response time). However, if the thermal properties of the medium are poor (e.g. still air) the response time can be 100 times greater.

For exposed measuring junctions, divide the values shown by 10. Thermocouple with grounded junction display response times some 20 to 30% faster than those with insulated junction. Very good sensitivity is provided by fine gauge unsheathed thermocouples. With conductor diameter in the range 0.025mm to 0.81mm, response times in the region of 0.05 to 0.40 seconds can be realized.

Sheath Outer Diameter (mm)	Types of Measuring Junction	Response Time in Seconds (in sec.)					
		100°C	250°C	350°C	430°C	700°C	850°C
6.00	Insulated	3.2	4.0	4.7	5.0	6.4	16.0
6.00	Earthed	1.6	2.0	2.3	2.5	3.15	8.0
3.00	Insulated	1.0	1.1	1.25	1.4	1.6	4.5
3.00	Earthed	0.4	0.46	0.5	0.56	0.65	1.8
1.5	Insulated	0.25	0.37	0.43	0.50	0.72	1.0
1.5	Earthed	0.14	0.17	0.185	0.195	0.22	0.8
1.00	Insulated	0.16	0.18	0.19	0.21	0.24	0.73
1.00	Earthed	0.07	0.09	0.11	0.12	0.16	0.6

Values shown are for a closed end sheath.

3.9.4 Immersion Length

Thermocouple assemblies are" tip" sensing devices which lends them to both surface and immersion applications depending on their construction. However immersion type must be used carefully to avoid error due to stema conduction from the process which can result in a high or low reading respectively.A general rule is to immerse into the medium to a minimum of 4 times the out side diameter of them sheath; no quantitative data applies but care must be exercised in order to obtain meaningful results.

The ideal immersion depth can be achieved in practice by moving the probe in to or out of the process medium incrementally; with each adjustment, not any apparent change in indicating temperature. The correct depth will result in no change in indicating temperature.

3.9.5 Surface Temperature Measurement

Although thermocouple assemblies are primarily tip sensing devices, the use of protection tubes renders surface sensing impractical. Physically, the probe does not lend it self to surface presentation and steam conduction would cause reading errors. If thermocouple is to be used reliably for surface sensing, it must be either exposed, welded junction from with very small thermal mass or be housed in a construction, which permits true surface contact when attaching to the surface. Locating a thermocouple on a surface can be achieved in various ways including the use of an adhesive patch, a washer and stud, a magnet for ferrous metal and pipe clips.

3.10. Advantage of Thermocouple

Industrial thermocouple, in comparison with other thermometers, has the following features:

1. Quick response and stable temperature measurement by direct contact with the measuring object.
2. If the selection of a quality thermocouple is properly made, wide range of temperature can be measured.
3. Temperature of specific spot or small space can be measured.
4. Since temperature is detected by means of EMF generated, measurement, adjustment, amplification, control, conversion and other data processing are easy.

5. Less expensive and better interchangeability in comparison with other temperature sensors.

6. The most versatile and safe for measuring environments, if a suitable protection tube is employed.

7. Rugged construction and easy installation.

3.11 Applications of Thermocouple

Thermocouples are suitable for measuring over a large temperature range, up to 2300°C. They are less suitable for applications where smaller temperature differences need to be measured with high accuracy, for example the range 0 - 100°C with 0.1°C accuracy. For such applications thermistors and resistance temperature detectors are more suitable. Applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes.

Some other applications are as follows :

1. Steel Industry
2. Cement Industry
3. Pharmaceutical Industry
4. Petrochemical Industry
5. Nuclear Industry
6. Power Industry
7. Laboratories
8. Furnace Industry

4
RTD Fundamentals

4.1 Introduction

The measurement of temperature using the resistance/ temperature characteristics of various materials were probably first to put use by Sir Williams Siemens in 1871, largely laid the foundations of modern resistance thermometry.

The resistance of material can be obtained from the given formula :

R = (ρ × L)/A

Where

R = Resistance(ohms)

ρ = Resistivity(ohm/cm)

L = Length(cm)

A = Cross sectional area(cm^2)

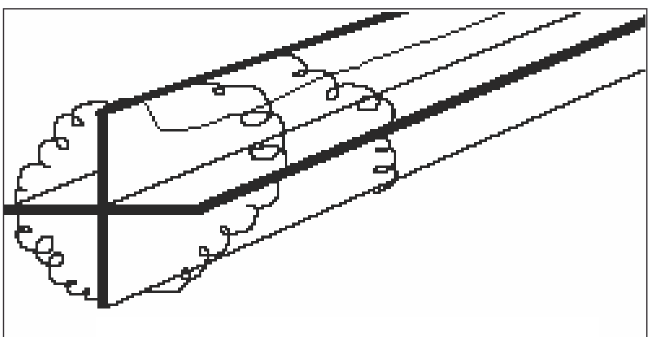
4.2 History Related to Resistance Temperature Detector

Sir William Siemens offered the use of platinum as the element in a resistance thermometer. His choice proved most favorable, as platinum is used to these days as the primary element in all high-accuracy resistance thermometers.

Platinum is especially suited to this purpose, as it can withstand high temperatures while maintaining excellent stability. As a noble metal, it shows limited susceptibility to contamination.

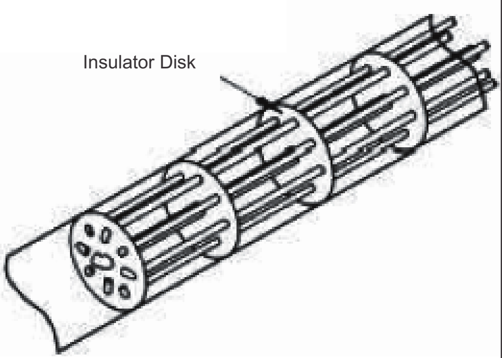
The classical resistance temperature detector (RTD) construction using platinum was proposed by C.H. Meyers in 1932. He used a helical coil of platinum on a crossed mica web and mounted the assembly inside a glass tube. This construction minimizes strain on the wire while maximizing resistance.

Although this construction produces a very stable element, the thermal contact between the platinum and the measured point is quite poor. This results in a slow thermal response time. The fragility of the structure limits its use today primarily to that of a laboratory standard.



MEYERS RTD CONSTRUCTION

Another laboratory standard has taken the place of Meyers' design. This is the bird-cage element proposed by Evans and Burns. The platinum element remains largely unsupported, which allows it to move freely when expanded or contracted by temperature variations.



Bird – Cage element

Strain-induced resistance changes over time and temperature are thus minimized, and the bird-cage becomes the ultimate laboratory standard. Due to the unsupported structure and subsequent susceptibility to vibration, this configuration is still a bit too fragile for industrial environment.

The platinum wire is bifilar wound on a glass or ceramic bobbin. The bifilar winding reduces the effective enclosed area of the coil to minimize magnetic pickup and its related noise. Once the wire is wound onto the bobbin, the assembly is then sealed with a coating of molten glass.

The sealing process assures that the RTD will maintain its integrity under extreme vibration, but it also limits the expansion of the platinum metal at high temperatures. Unless the coefficients of expansion of the platinum and the bobbin match perfectly, stress will be placed on the wire as the temperature changes, resulting in a strain-induced resistance change. This may result in a permanent change in the resistance of the wire. There are partially supported versions of the RTD which offer a compromise between the bird-cage approach and the sealed helix. One such approach uses a platinum helix threaded through a ceramic cylinder and affixed via glass-frit. These devices will maintain excellent stability in moderately rugged vibrational applications.

4.3 Resistance Temperature Detector (RTD)

4.3.1 Introduction

The RTDs resistance vs temperature characteristics are stable, reproducible, and have a near linear positive temperature coefficient from 200 to 800°C. These attributes establish RTDs as a de-facto industry standard. Temperature is determined by measuring resistance and then using the RTD.s .R vs T. characteristics to extrapolate temperature. The superior sensitivity and stability of these devices, in comparison to thermocouples, give them important advantages in low and intermediate temperature ranges. In addition, resistive devices often simplify control and readout electronics.

Resistance thermometers may be called RTD's (resistance temperature detectors), PRT's (platinum resistance thermometers), or SPRT's (standard platinum resistance thermometers).

The chemical stability, availability in pure form, and highly reproducible electrical properties, has made Platinum the metal of choice for RTD's which are made of either IEC/DIN-grade platinum or reference-grade platinum. The difference lies in the purity of the platinum. The IEC/DIN standard is pure platinum that is intentionally contaminated with other platinum.

Equation of RTD

At 0 ºC, A platinum RTD has a resistance of 100Ω & a temperature co-efficient of about 0.00385 Ω/ Ω / ºC. These non-linearties are described in **Callender- Van Duesen** equation. This equation consists of both a linear portion & a non- linear portion.

Range -200 to 0°C : $R(t)\,[\Omega] = R_0\,(1 + At + Bt^2 + C\,(t - 100°C)\,t^3)$

Range 0 to 850°C : $R(t)\,[\Omega] = R_0\,(1 + At + Bt^2)$

With: R_0 is resistance at 0 °C

A = 3, 9083 x 10^{-3}°C^{-1}

B = -5,775 x 10^{-7}°C^{-2}

C = -4,183 x 10^{-12}°C^{-4}

TEMPERATURE COEFFICIENT OF RESISTANCE (α)

Temperature Coefficient of Resistance (TCR) has many definitions. For resistance thermometers, TCR is normally defined as the average resistance change per °C over the range 0 to 100°C, divided by R_0^0C.

TCR values for the common elements are:

TCR (α) (Ω/ºC) = (R_{100} – R_0) / (100 ×R_0)

Where,

α = Temperature Coefficient (Ω/Ω/°C)

R_{100} = RTD resistance at 100°C

R_0 = RTD resistance at 0°C

TCR values for the common elements are:

Copper= {(12.897-9.035)/ (9.035)}/ (100) = 0.00427 Ω/ Ω/°C

Nickel- Iron = {(917.33 -604)/604}/ (100) = 0.00518 Ω/ Ω/°C

Nickel = {(200.64 -120)/120}/100 = 0.00672 Ω/ Ω/°C

Platinum = {(138.50 - 100)/ 100}/ 100 = 0.003850 Ω/ Ω/°C

There are four primary curves specified for platinum:

1. 0.003926/°C : Standard platinum resistance thermometers are the only PRT's that can achieve this TCR. They must have high purity platinum wire (99.999% or better) wound in a strain-free configuration.

   The stresses introduced in manufacturing, lower the TCR of ordinary industrial models.

   Several manufacturers offer industrial platinum thermometers with nominal TCR of 0.00392; TCR's around 0.003923 are achieved regularly.

2. 0.003911/°C : This TCR is sometimes called the "U.S. Industrial Standard." Ceramic elements impose strain on platinum wire. It is lower than laboratory standards as the typical construction of high temperature.

3. 0.00385/°C : DIN 43760, IEC 751, and other national and international specifications mandate this TCR.

4. 0.00375/°C : Elements with 0.00375 TCR, intended for low-cost applications.

There are few inherent advantages in specifying any particular TCR over another. Laboratory systems traditionally use reference standards with the highest-grade platinum, but industrial specify may aim instead for the greatest degree of standardization. In this case, 0.00385 TCR will be compatible with the length number of manufacturers.

4.3.2 RTD Materials

The criterion for selecting a material to make an RTD is:

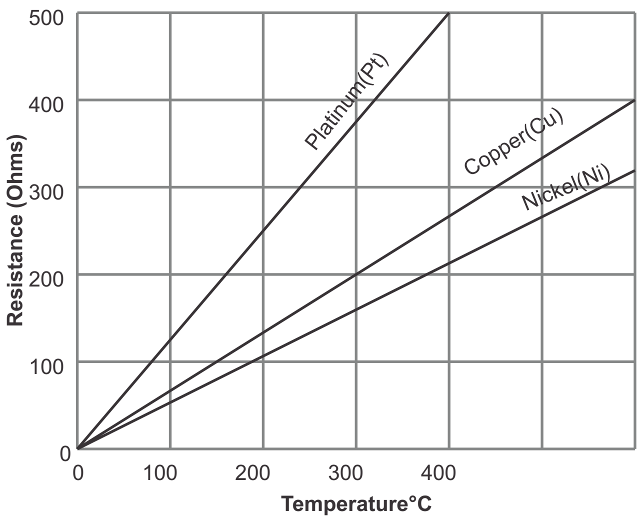
- ✓ The material must be malleable so that it can be formed into small wires.
- ✓ It must have a repeatable and stable slope or curve.
- ✓ The material should also be resistant to corrosion.
- ✓ The material should be low cost.
- ✓ It is preferred that the material have a linear resistance verses temperature slope.

Some of the common RTD materials are platinum, copper, nickel, Balco (an alloy of 70% nickel and 30% iron). These metals have the advantage that they can be manufactured to a very high degree of purity and are, consequently, available with highly reproducible temperature/resistance characteristics. These metals can also be drawn to a fine diameter wires required in resistance thermometry.

Table : Characteristics of several metals used as RTD

Element Material	Temperature Range(°C)	Resistance Ratio(R_{100}/R_0)	Resistivity x 10^{-8}(Ω.m)	Relative Cost	Linearity Deviation (0-100°C)
Platinum	-200 to 850	1.3925 to 1.385	11	1100	+0.12
Copper	-200 to 260	1.427	1.72	1	0
Nickel	-80 to 300	1.672	7.8	20	-1.61
Balco	-200 to 230	1.518	20	15	-1.17

As shown in table, although copper is cheapest, it also has the lowest resistivity and therefore requires inconveniently large sensing elements. On the other hand, even as nickel and nickel alloy have high resistivity, their resistance versus temperature coefficients are non-linear. They are also sensitive to strain and their resistivities suffer from an inflexion around the Curie point (358ºC) that makes the deviation of their resistance/ temperature expressions more complicated.



This platinum which not only has a high resistivity (more than six times that of copper) but also a high degree of stability and a wide temperature range. Although platinum is expensive it can be drawn into fine wires or strips and we only require small amounts for manufacturing RTDs. As a noble metal, it has minimum susceptibility to contamination.

The presence of impurities is undesirable since diffusion, segregation and evaporation may occur in service, resulting in a lack of stability. The resistivity is also sensitive to internal strains. Thus, it is essential that the platinum should remain in a fully annealed condition i.e. it should be annealed at a temperature higher than the maximum temperature of service.

4.3.3 Temperature Rating

The maximum temperature rating for RTD's is based on two different factors. First is the element material. Platinum RTD's can be used as high as 650°C (1202°F). Other materials are much lower in temperature rating and vary from material to material. The other determining factor for temperature rating is probe construction. There are construction considerations used in each of these different styles making them ideal for use in each of those ranges. No one style is good for all ranges.

4.4 Types of RTD

Platinum RTDs typically are provided in two classes; **Class A and Class B.**

Class A is considered high accuracy and has an ice point tolerance of ±0.06 ohms.

Class B is standard accuracy and has an ice point tolerance of ±0.12 ohms. Class B is widely used by most industries.

The accuracy will decrease with temperature. Class A will have an accuracy of ±0.43 ohms (± 1.45°C) at 600°C and class B will be ± 1.06 ohms (± 3.3°C) at 600°C. The chart below shows the tolerance versus temperature (IEC 751).

Other accuracy classes like 1/3, 1/5, 1/10 of class B are available.

Table : Tolerance table for type of RTD according to IEC 751

Temperature	1/10 Din (±°C)	1/5 Din (±°C)	1/3 Din (±°C)	Class A (±°C)	Class B (±°C)
-100°C	0.080	1.160	0.267	0.350	0.800
-50°C	0.055	0.110	0.183	0.250	0.550
0°C	0.030	0.060	0.100	0.150	0.300
50°C	0.055	0.110	0.183	0.250	0.550
100°C	0.080	0.160	0.267	0.350	0.800
150°C	0.105	0.210	0.350	0.450	1.050
200°C	0.130	0.260	0.433	0.550	1.300
250°C	0.155	0.310	0.517	0.650	1.550
300°C	0.180	0.360	0.600	0.750	1.800
350°C	0.205	0.410	0.683	0.850	2.050
400°C	0.230	0.460	0.767	0.950	2.300

Platinum resistance temperature sensors (PRT) They offer excellent accuracy over a wide temperature range(from -200 to +850°C).

Other resistance value options

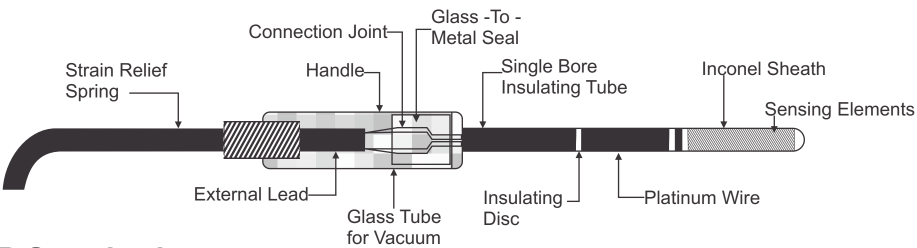
RTD elements are also available with resistances of 200, 500, and 1000 Ω at 0°C. Such type of RTDs is normally known as PT200, PT 500, and PT 1000 respectively. These RTDs have the same temperature coefficients as previously described, but because of their higher resistances at 0°C, they provide more resistance change per degree, allowing for greater resolution.

Other standards for Pt 100Ω RTDs are shown :

Standard	R_{100}/R_0 Ratio
DIN 43760	1.385
U.S. Lab Spec.	1.3926
U.S. Industrial Spec.	1.3911
Canadian Spec.	1.3889
MIL - T -24388	1.3924
Japanese JIS C 1604	1.3916

Standard Platinum RTDs (SPRTs)

The ITS-90 (International Temperature Scale of 1990- used as a worldwide practical temperature scale in national metrology labs like NIST, NPL) is made up of a number of fixed reference points with various interpolating devices used to define the scale between points. A special set of PRTs, called SPRTs, are used to perform the interpolation in such labs over the ranges 13.8033 K (Triple point of Equilibrium Hydrogen) to the Freezing point of silver, 971.78 °C.



4.5 RTD Standards

There are two standards for platinum RTDs: The European standard (also known as the DIN or IEC standard) and the American standard.

The European standard, also known as the DIN or IEC standard, is considered the world-wide standard for platinum RTDs. This standard, DIN/IEC 60751 (or simply IEC751), requires the RTD to have an electrical resistance of 100.00 Ω at 0°C and a temperature coefficient of resistance (TCR) of 0.00385 Ω/Ω/°C between 0 and 100°C. There are three resistance tolerances for Thin Film

RTDs specified in IEC60751:

Class AA (Formerly 1/3B) = ± (0.1+0.0017×t) °C or 100.00 ± 0.04Ω at 0°C

Class A = ± (0.15+0.002×t) °C or 100.00 ± 0.06Ω at 0°C

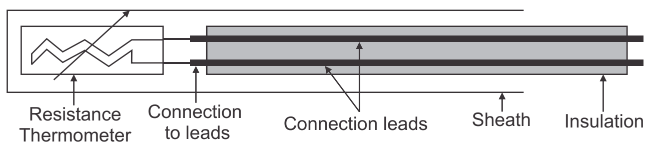
Class B = ± (0.3+0.005×t) °C or 100.00 ± 0.12Ω at 0°C

Also, one special class not included in DIN/IEC60751:

Class 1/10B = ±1/10 (0.3+0.005×t) °C or 100.00 ± 0.012Ω at 0°C

4.6 Construction of RTD

The RTD elements nearly always require insulated leads attached. At temperatures below about 250 °C PVC, silicon rubber or PTFE insulators are used. Above this, glass fiber or ceramic are used. The measuring point, and usually most of the leads, requires a housing or protective sleeve, often made of a metal alloy which is chemically inert to the process being monitored. Selecting and designing protection sheaths can require more care than the actual sensor, as the sheath must withstand chemical or physical attack and provide convenient attachment points.



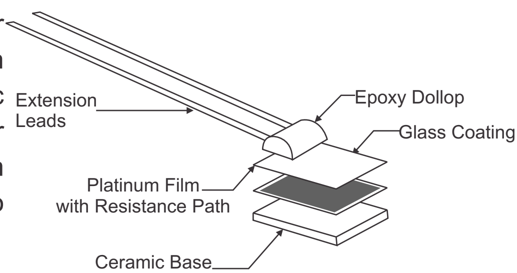
RTD construction

RTD's are manufactured in 3 basic types of construction. Each of these different types has advantages and disadvantages.

4.6.1 Platinum Thin Film RTD

The thin film style of RTD is probably the most popular design because of their rugged design and low cost. The thin film element is manufactured by coating a small ceramic chip with a very thin (.0001") film of platinum and then laser cutting or chemical etching a resistance path in the platinum film. The element is then coated with a thin layer of glass to protect it from harmful chemicals and gases.

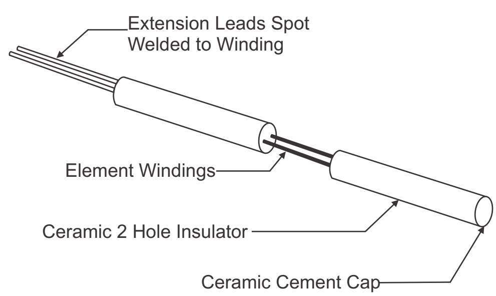
Larger extension lead wires are spot welded to the chip and this junction is then covered with a drop of epoxy to help hold the wires to the element.



Platinum thin film RTD

4.6.2 Inner Coil Wire Wound RTD

This type of element is normally manufactured using platinum wire. Very small platinum wire (0.02 mm) is coiled and then slid into a small 2 holes ceramic insulator. Larger extension leads are then spot welded to the ends of the platinum wire and cemented in place. Some manufacturers backfill the bores of the insulator with ceramic powder, once the coils have been inserted. This keeps the coils from moving and shorting against each other. The end opposite the extension leads is capped with ceramic cement also.

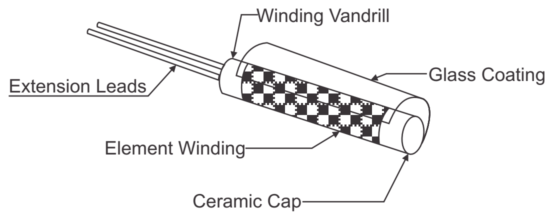


Inner coil wire wound RTD

4.6.3 Outer Wound RTD Element

The outer wound RTD element is made by winding the sensing element wire around a center mandrill, which is usually made of ceramic. This winding is then coated with glass or some other insulating material to protect and secure the windings. The winding wires are then spot welded to extension leads and secured to the body with ceramic cement or epoxy.

Each of the types has their advantages. The thin film is the least expensive to manufacture and also the most rugged. They can also be manufactured in very small sizes. The inner coil wire wound style is the most accurate. It is however, more expensive to manufacture and does not perform well in high vibration applications. The outer wound element is similar in cost to the inner coil element. It is not as accurate as the inner coil style but is more rugged.



Outer wound RTD element

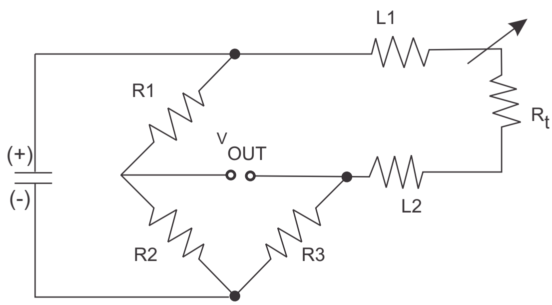
4.7 Lead Wire Configurations

RTDs are available with three different lead wire configurations. The selection of lead wire configuration is based on desired accuracy and instrumentation to be used for the measurement.

Two Wire RTD

The two wires RTD is the simplest wire configuration. One wire is attached to each side of the element. A measure can be taken by any device equipped to measure resistance, including basic Volt Ohm Meters (VOM).

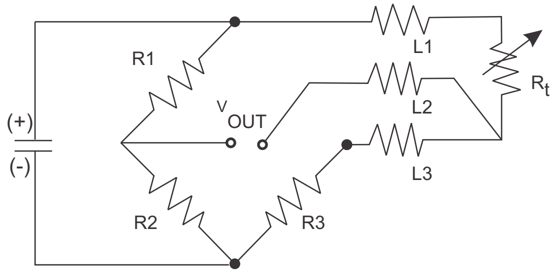
This is the least accurate way of measuring temperature, due to the fact that the lead wire resistance is in series with the sensing element. The lead wire is at a different temperature than the sensing element and also has different resistance verses temperature characteristics. The longer the lead wire greater will be the effect on the measurement.



Two Wire RTD

Three Wire RTD

The three wires RTD is the most popular configuration for use in industrial applications. In order to minimize the effects of the lead resistances, a three-wire configuration can be used. Using this method the two leads to the sensor are on adjoining arms. There is a lead resistance in each arm of the bridge so that the resistance is cancelled out, so long as the two lead resistances are accurately the same. This configuration allows up to 600 meters of cable.



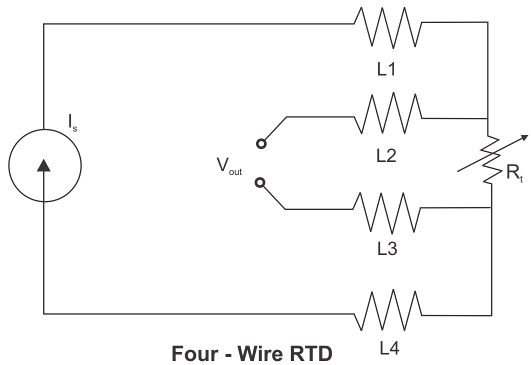
Three Wire RTD

When used correctly, the three wire configuration eliminates the series resistance. This permits an accurate measurement of the sensing element. Two of the leads are connected to one side of the sensing element and the single lead to the other side. The resistance in L1 and L3 should be matched as close as possible, this will cause the lead resistance to cancel themselves. The color code for a three wire RTD is two red wires and one white.

Four Wire RTD

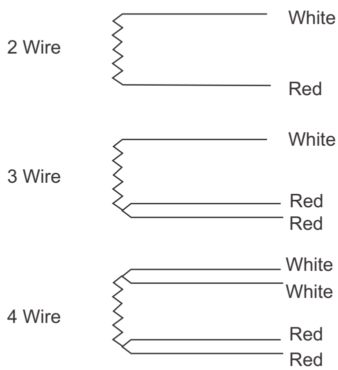
A four wire RTD is the most accurate method to measure an RTD. It is primarily used in laboratories and is seldom seen in an industrial application. The four-wire resistance thermometer configuration increases the accuracy and reliability of the resistance being measured: the resistance error due to lead wire resistance is zero.

A four wire RTD circuit removes the effect of mismatched resistances on the lead wires. A constant current is passed through L1 and L4, L2 and L3 measure the voltage drop across the RTD element. The color code for a four wire RTD is usually two red wires and two white wires. The following diagram illustrates a typical four wire measurement.



Four - Wire RTD

LEAD CONFIGURATION & COLOUR CODE



2 Wire	Used where lead length is short. There is no compensation for resistance of lead wires.
3 Wire	Most common type of RTD assembly. Typically connected to standard bridge circuit, which allows lead wire resistance to be compensated.
4 Wire	where higher accuracy is demanded. Lead wire resistance errors are eliminated in this configuration by measuring the voltage across the RTD element supplied with a constant current.

4.8 Mineral Insulated RTD

Mineral-Insulated resistance thermometers (M.I.) are equipped in general with Platinum-measuring resistors Pt100 Ω to DIN IEC 751. The inner (Cu) conductors are embedded in a closely compacted, inert mineral powder (MgO), the measuring resistor will be connected to the inner conductors, is also embedded and is surrounded by the metal sheath to form a hermetically sealed assembly. Some times inner conductor of constantan and nickel are also used.

The sheath functions as a useful protective cover in many situations. They are applied in locations where fast response, reduced space and or vibration resistance is a need. They can be furnished with a fixed cable or with a special plug which allows rapid fitting or exchange.

Mineral-insulated RTD temperature probes consist of a flexible, thin-walled stainless steel mineral-insulated cable, in which low ohmic conductor copper wires are embedded in pressed, heat resistant magnesium oxide.

The temperature probe is connected to the wires of the internal conductors and accommodated in a stainless steel sheath. Thermowell and mineral insulated cable are welded to one another.

The good heat transition between the sheath and the temperature probe permits short response times and high measuring accuracy. The vibration resistant (shake proof) design guarantees a long operating life. Temperature measurements at measuring points difficult to access are possible thanks to the flexible mineral-insulated cable. The smallest bending radius is 5 times the outer diameter.

Metal Sheathed RTD

1) It comprises of a thin-walled and flexible mineral insulated sheath cable made up of stainless steel.

2) The cable contains low resistance inner wires made of copper embedded in pressed fireproof magnesium oxide.

3) The temperature sensor is connected to the inner wires and fitted in a protective tube.

4) Protective tube and sheathed cable are welded together hermetically.

5) Good heat transfer between protective tube and temperature sensor allows fast response time and high measuring accuracies.

6) The flexible probe tube allows temperature measurement at locations that are not easily accessible.

7) They are used in difficult measurement application with strong vibrations as well as at all measuring positions where flexibility and ease of replacement are needed.

8) Areas of application are to be found in chemical plants, power stations, motors, as well as in machine construction and building installation and in general industrial applications.

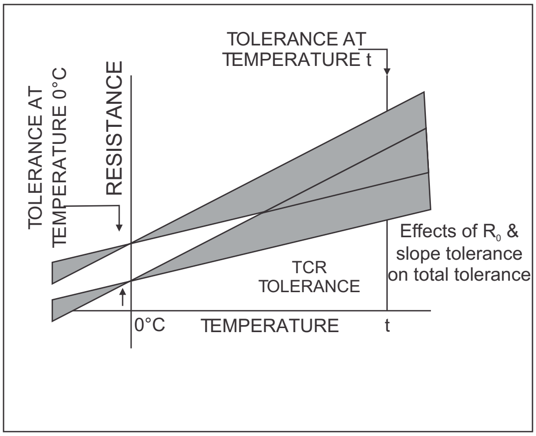
4.9 Potential Sources of Error with Resistance Thermometers

Resistance thermometer systems are susceptible to three types of errors: The inherent tolerances built into the thermometers, gradients between the thermometer and the medium to be sensed, and errors introduced along the path between the sensor and readout or control instrument. Some sources of error are electrical; others result from the mechanical construction of the thermometer.

Interchangeability/Conformity:

Conformity specifies the amount of resistance a thermometer is allowed to deviate from a standard curve (such as the curve produced by the Callendar-Van Dusen equation).

A tolerance at the reference temperature, usually 0°C, and a tolerance on the slope or TCR. Below shown figure states that a resistance thermometer conforms most closely to its curve at the reference temperature, while the resistance fans out above and below this



reference.

For example, IEC 751, Class B, requires calibration within 0.12 (0.3°C) at 0°C, but allows TCR to deviate from nominal 0.00385 by ±0.000012 /°C. Thus, tolerance spreads to 0.8°C at 100°C, 1.3°C at 200°C, and on up to 3.8°C at 700°C. Interchangeability between two thermometers is no more than twice the value of there Conformity. Commercial platinum resistance thermometer elements are available with extremely tight tolerances, to within 0.026°C in some cases. When interchangeability is an overriding consideration, the specified may consider other means to achieve it. For example, manufacturers may alter their calibration procedures to fix the reference temperature and tightest tolerance at a point other than 0°C.

Sensitivity

The resistance change per degree change in temperature is a function of base resistance and TCR (Temperature Coefficient of Resistance).

Although a thermometer with higher sensitivity is not necessarily more accurate, a larger signal simplifies output electronics and is less susceptible to lead wire effects and electrical noise. In addition, a larger resistance produces the same voltage output with less measuring current, which helps to limit self heating of the thermometer element.

Insulation Resistance

If the sensing element and leads are not completely insulated from the case, a shunting effect occurs in which the case becomes a parallel resistor and lowers apparent readings. In most industrial thermometers, with specified insulation Resistances in the 100-MΩ ranges, error approaches zero. The manufacturer must take care to seal water-absorbing materials. The shunting effect decreases with low-resistance elements, which accounts. The shunting effect decreases with low-resistance elements, which accounts for the use of 25.5 PRT's in laboratory measurements.

Self-Heating

A resistance thermometer is a passive resistance sensor; it requires a measuring current to produce a useful signal. Because this measuring current heats the element wire above the true ambient temperature, errors will result unless the extra heat is dissipated.

Self-heating is most often expressed in mW/°C, which is the power in mill watts (1000 I2 R) required to raise the thermometers internal temperature by 1°C. The higher the mW/°C figure, the lower the self-heating. As an example, assume a 5 mA measuring current is driven through 100 platinum RTD at 100°C. Self-heating is specified as 50 mW/°C in water moving at 3 ft/sec. The amount of heat generated is:

$$1000 \text{ mW} \times (0.005 \text{ A})^2 \times (138.5) = 3.5 \text{ mW}$$

The self-heating error is:

$$(3.5 \text{ mW}) / (50 \text{ mW/°C}) = 0.07\text{°C}$$

The generated heat increases with higher sensor element resistance (when a constant current measurement device is used), or with increasing measuring current.

The resulting error is inversely proportional to the ability of the thermometer to shed extra heat; which in turn depends on thermometer materials, construction, and environment.

The worst self-heating occurs when a high resistance is packed into a small body. Thin film elements, with little surface area to dissipate heat, are an example. Self-heating also depends on the medium in which the thermometer is immersed. Error in still air may be over 100 times greater than in moving water.

Time Constant

A time constant indicates the responsiveness of a resistance thermometer to temperature change. A common expression is the time it takes a thermometer to reflect 63.2% of a step temperature change in moving water. Response speed depends on the mass of the thermometer and the rate at which heat transfers from the outer surface to the sensing element. A rapid time constant reduces errors in a system subject to rapid temperature changes.

Repeatability

The degree of accord between two successive readings with a thermometer is its repeatability. Loss of repeatability results from permanent or temporary changes to the resistance characteristics of the element and may be caused by exposing the thermometer to temperatures at or beyond the endpoints of its specified range. A repeatability test cycles the thermometer between low and high temperatures; any changes to R are noted. A typical repeatability rating for 0°C industrial platinum resistance thermometers is ±0.1°C.

Stability

Stability is long-term drift in thermometer readings. A typical specification would limit drift to 0.1°C per year for rated operation. Normal services at points well within the temperature rating typically cause much less drift. Drift is a consequence of the element material, with platinum being the most stable; encapsulating materials, which could contaminate the element; and mechanical stress placed on the element by expansion of winding bobbins or other supporting structures.

Shock and Vibration

Mechanical shock and vibration can alter thermometer readings or cause complete failure. In fact, stability and ruggedness are somewhat exclusive. A laboratory thermometer designed for maximum stability contains an unsupported element, which is far too fragile for industrial use. The elements of most industrial resistance thermometers are fully supported by a bobbin or packing material, and therefore stand up quite well to extreme environments. More likely to suffer are lead wire transition points, which should be properly immobilized. A typical RTD will meet a specification allowing shock of 100 G's of 8 milliseconds duration and vibration of 10 to 2000 Hz at 20 G's.

Packaging and Thermal Transfer

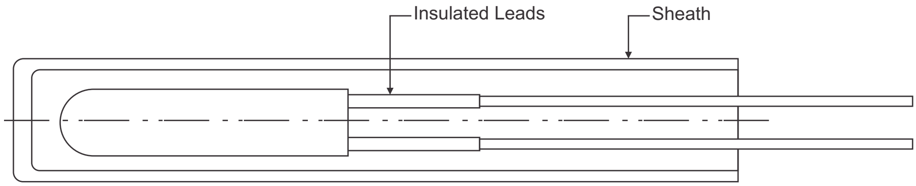
Sheaths and other structures surrounding resistive elements should maximize heat transfer from the sensed medium, minimize heat transfer from ambient which can alter readings, and provide necessary protection of the elements.

Proper materials and construction can dramatically improve reading accuracy. One strategy practicable only with wire-wound resistance thermometers versus thermistors, thermocouples, and solid-state devices are temperature averaging. An element may be wound to average temperature over lengths of up to 100feet.

4.10 Industrial RTD Probes

The encased probe is the standard resistance thermometer configuration for industrial process control and machinery protection. Most probe cases are stainless steel or Inconel to withstand high temperatures, although other materials offer advantages at intermediate ranges.

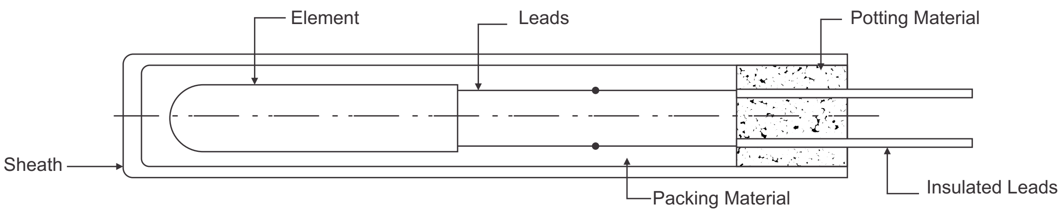
For example, the tip-sensitive probe of Figure a copper-alloy tip which conducts heat 20 times better than stainless steel. This design improves thermal contact with sensed surfaces and reduces errors from conduction along the sheath.



Tip sensitive probe

Standard probe diameters range from 0.125. to 0.250. Smaller probes respond faster when directly immersed, but larger probes may fit more snugly in standard thermowells. Probe lengths range from a few inches to ten feet or more.

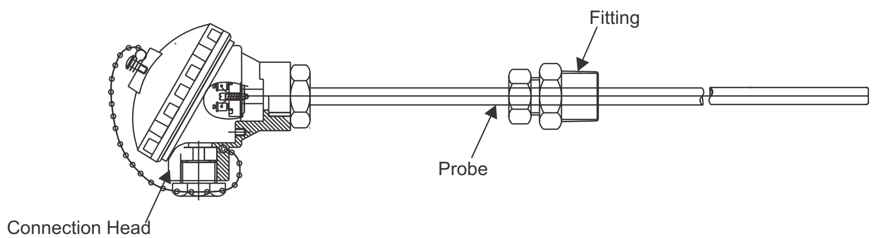
Figure shows the construction of a high temperature probe. The element fits in the tip, surrounded by high temperature powder or cement. Extension leads, normally uninsulated, extend back from the element and are encapsulated by powder, cement, or bored ceramic spacers. External leads, often insulated with Teflon or glass braid, are potted with cement at the entry point to seal against moisture.



High Temperature Probe

4.11 Probe Assemblies

A wide variety of mounting fittings and accessories aid probe installation. Selection depends on the nature of the medium being sensed and cost requirements. Direct immersion of a probe into a liquid requires a fitting with a pipe thread, which may be adjustable or welded on the probe. Figure shows a typical assembly, with one thread for mounting the probe and another for a connection head. Connection heads provide a transition between probe leads and external signal wires.



Typical Probe Assembly

Mounting in a solid material is best accomplished with a spring-loaded holder, which may be fixed or adjustable. Spring loading provides good contact of the probe tip against the bottom of the hole and dampens potentially damaging vibration. When liquids are particularly corrosive, under high pressure, or fast-flowing, a thermowell may be necessary. A thermowell is a tube, closed at one end, which protects the probe and allows its removal without breaking the liquid seal. Many materials and styles are available to match application requirements. Thermowells drilled from solid bar stock provide the highest pressure ratings, but welded models cost much less.

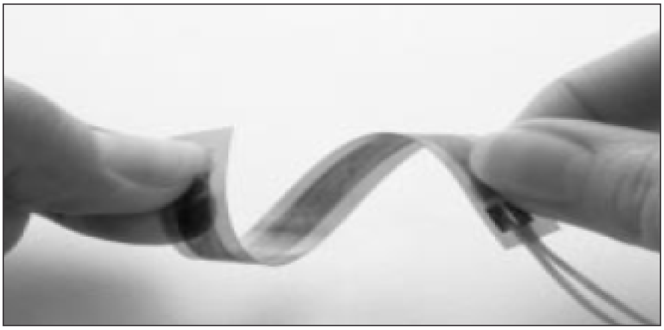
4.12 Flexible Resistance Thermometers

The encased probes described above do not adapt well to sensing flat surfaces. Unlike thermocouple junctions, which can be welded directly to metal surfaces, resistance thermometers present a certain amount of bulk; and heat losses to ambient air may affect readings. Small flat elements, such as thin films, may mount on surfaces, but fragile element and lead wire connections make installation difficult.

Figure shows a flexible resistance thermometer with a wire-wound sensing element sandwiched between insulating layers. It conforms closely to sensed surfaces, and has thin insulation to readily transmit heat to the sensing element. The wire element may be wound to nearly any size to average out temperature gradients, and the flexible construction can withstand extreme shock and vibration.

4.13 Special Purpose Resistance Thermometers

Resistance thermometers readily adapt to most process control and thermal equipment designs. The user may specify cases with axial leads for circuit board mounting, flat packages for clamping to surfaces, miniature cases for embedment into metal blocks, and any sheaths and fittings which can be produced by a machine shop. In addition, wire windings may be configured to sense over large areas.



Flexible resistance thermometer

4.14 Where to use Resistance Thermometers

In summary, resistance thermometers offer the greatest benefits relative to other thermometer types in these situations:

- ✓ Accuracy and stability are the foremost goals of the Application
- ✓ Accuracy must extend over a wide temperature range
- ✓ Area, rather than point, sensing improves control
- ✓ A high degree of standardization is desirable

4.15 Advantages and Limitations

Advantages of platinum resistance thermometers

- ✓ High accuracy

- ✓ Low drift
- ✓ Wide operating range
- ✓ Suitable for precision applications

Limitations

- ✓ RTDs in industrial applications are rarely used above 660 °C. At temperatures above 660 °C it becomes increasingly difficult to prevent the platinum from becoming contaminated by impurities from the metal sheath of the thermometer. This is why laboratory standard thermometers replace the metal sheath with a glass construction. At very low temperatures, say below -270 °C (or 3 K), due to the fact that there are very few photons, the resistance of an RTD is mainly determined by impurities and boundary scattering and thus basically independent of temperature. As a result, the sensitivity of the RTD is essentially zero and therefore not useful.
- ✓ Compared to thermistors, platinum RTDs are less sensitive to small temperature changes and have a slower response time. However, thermistors have a smaller temperature range and stability.

5
Protection Tubes, Thermowell, Fittings and Terminations

5.1 Protection Tubes

Sheath material ranges from mild and stainless steel to refractory oxides (Ceramics) and a variety of exotic material including rare metals. Sensor inserts are fabricated unit which is comprised by a sensor and a terminal base; the sensor is housed in a stainless steel insert tube, usually of 6 or 8mm diameter and, then it is inserted into the actual protection tube. Good sheathing with physical contact between the insert tip and sheath end is essential to ensure good heat transfer. Spring contact is used in the terminal base to maintain this contact. This arrangement facilitates easy replacement of the sensor whenever required. In the case of a mineral insulated thermocouple or Pt100, the sensor is designed as an integral part with the insert tube.

5.1.1 Metallic or Non-Metallic Sheathing

Metallic tube, most commonly stainless steel, has mechanical advantage and higher thermal conductivity; they are generally immune to thermal shock. Metallic sheath can be used at temperature up to 1150°C. Ceramics are superior when high purity is required to avoid sensor or product being contaminated at elevated temperature.

5.1.2 Ceramic Sheath with Thermocouple Element

Ceramic sheath's main application ranges between 1000 to 1800 °C. They may be in direct contact with the medium or may be used as a gas-tight inner sheath to separate the thermocouple from the actual metal protection tube. They should be mounted in hanging position above 1200°C to prevent distortion or fracture due to bending stresses. Even hairline cracks can lead to contamination of the thermocouple resulting in drift or failure. The wall thickness of the material is also important; thin walled tube is preferable to larger wall thickness. Cracks frequently developed if they are given excessively rapid temperature changes when they are quickly removed from hot furnace.

Protection Tubes

Caution: Due to high thermal conductivity of the metal tubes, minimum insertion length should be more than twenty five times of its overall diameter to eliminate heat conduction error.

(A) Metallic Protection Tubes

Sr. No.	Material	Max./Operating Temperature (°C)	Feature
1	304 S.S.	980°C	Widely used as a common protection tube against heat and corrosion but not recommended for use in the presence of sulphur or reducing flame. Subject to stress and “pit” corrosion.
2	321 S.S.	980°C	Higher corrosion resistance than 304 S.S. because of its Ti content to prevent carbon precipitation. Excellent resistance to grain boundary corrosion after welding due to less carbon precipitation.

Sr. No.	Material	Max./Operating Temperature (°C)	Feature
3	316 S.S.	980°C	Contains Mo and has excellent resistance to corrosives, heat, acids and alkalis.
4	316L S.S.	980°C	Less carbon content than 316 s.s. an has better resistance to grain boundary corrosion, Resistant to "pit" corrosion.
5	310 S.S.	1,000°C	High Ni-Cr content and good high temperature strength with resistance to oxidation at high temperature high mechanical strength
6	446 S.S.	1,050°C	Excellent resistance to oxidizing and reducing flames containing sulphur. Suitable for use in non-ferrous molten metals and other high temperature application, but less mechanical strength.
7	Inconel 800	1000°C	Excellent to high temperature oxidizing atmosphere and thermal shock. Above 10 times longer service life than 304 S.S. against high temperature corrosion.
8	Inconel 825	1000°C	An improved version of inconel 800. All round superior alloy for high temperature applications, particularly in oil refineries against organic sulfides, hydrogen sulfide and sulphur combustion products.
9	Inconel 600	1,050°C	Excellent resistance to oxidizing and reducing atmospheres at high temperature. But sulphurous atmospheres should be avoided. Immune to stress and "pit" corrosion.
10	Inconel 601	1,050°C	superior oxidation resistance at high temperature to inconel 600, by virtue of strong bonding of metal oxide film.
11	Inconel 625	1,050°C	Improved strength and stress rupture properties up to 980°C by MO and CB additional and immune to chloride stress corrosion cracking.
12	253 MA	1000°C	Superior Oxidation resistance to 310SS at high temperature due to formation of dense and tight oxide layer by silicon and cerium additions. can be used in the sulphurous atmospheres.
13	UMCO	Oxi. 1150°C Red. 1200°C	Excellent resistance to heat, corrosion and abrasion. One of the best alloy against high temperature sulphur bearing atmospheres.
14	Kanthal A1	1100°C	Good resistance to high temperature oxidation but becomes brittle due to recrystallization. Poor mechanical strength above 850°C.
15	Hastelloy B	Oxi. 500°C Red. 760°C	Excellent resistance to heat in corrosion, especially to HCl and H_2SO_4.
16	Hastelloy C-276	1000°C	Excellent resistance to high temperature oxidizing and reducing atmospheres and also Cl_2 gases.

Sr. No.	Material	Max./Operating Temperature (°C)	Feature
17	Hastelloy X	1100°C	Excellent resistance to oxidizing and carburizing atmospheres at high temperatures. Better machinability and weldability than other Hastelloy alloys.
18	Monel	Oxi. 500°C Red. 600°C	Excellent resistance to water vapor and sea water at high temperature and corrosion.
19	Platinum	1,650°C	The platinum group metals are well suited for use at extremely high temperature under mechanical loads and simultaneous corrosive attack. They have high melting points, excellent chemical stability and are highly resistant to oxidation. Used for molten glass application as hardened PtRh alloy.
20	Titanium	Oxi. 250 Red. 1000°C	Superior corrosion resistance in cryogenic temperature but at high temperatures easily oxidized and becomes brittle.
21	Tantalum	Oxi. 300 Red. 2,200°C	Excellent heat-resistant material with high resistance to all acids but apt to severe oxidation and embitterment in air at high temperature. Tantalum is outranked by tungsten for high temperature strength.
22	Molybdenum	Oxi. 400 Red. 2,000°C	Excellent mechanical strength up to 1500°C for applications under inert, reducing and vacuum atmosphere. Resistance to metal vapours at high temperature but react with carbon or graphite. Should not be used in air or oxygen containing gases.

(B) Non-Metallic Protection Tubes

Sr. No.	Material	Max./Operating Temperature (°C)	Feature
1	refractory oxide recrystallised Al_2O_3- 99.7% (710)	1750°C - max.	Good choice for rare metal thermocouple. Good resistance to chemical attack. Mechanically strong but severe thermal shock should be avoided.
2	Silicon carbide	1500°C - max.	Good level of protection even in severe conditions. Good resistance to reasonable level of thermal shock. Mechanically strong when tick wall is specified but become brittle when aged. Unsuitable for oxidizing atmosphere but resists fluxes.
3	Silicon Nitride (Si_3N_4)	1,350°C	Excellent thermal shock resistance. Less corrosion to acids and alkalis. High hardness. Fairly good resistance against most of molten metals.

Sr. No.	Material	Max./Operating Temperature (°C)	Feature
4	Cermet (Chrome-Alumina)	1,300°C	77% Alumina -23% Chrome Excellent resistance to heat and abrasion. Recommended for temperature measurement of molten copper and other nonferrous metals.
5	Quartz	1,000°C	Excellence to thermal shock but fragile. Poor resistance to alkalis but good to acids. Less gas-tightness in hydrogen and reducing gases. High thermal conductivity.
6	60% Alumina	1,500°C	60% alumina-40% Silica Sintered alumina. Better than Pt2 but slightly less thermal shock resistance. recommended for use in heating furnace and regenerator, impervious.
7	Self Bonded Silicon Carbide	1,650°C	99% SiC. Very low porosity. Excellent resistance to thermal shock, corrosion and abrasion at high temperatures. recommended for use in oxidizing and reducing atmosphere upto 1650°C but attacked by water vapor.
8	Nitride Bonded Silicon Carbide	1,550°C	78%SiC+3%SiO_2+18%Si_3N_4(Si_2ON_2) Excellent performance superior to Y3 SiC but contains Si_3N_4. Most suitable for use in molten aluminium, against most of molten metals.
9	Tungsten Carbide	Below 350°C	Good mechanical strength and high abrasion resistance.

Note: Operating and maximum temperatures of the above tubes vary depending on the measuring environments.

5.1.3 Insulation Material

Mostly used insulation materials are given below:

Sr. No.	Insulation Material	Max./Operating Temperature (°C)	Feature
1	Alumina Al_2O_3	1,900°C	High-purity aluminum oxide is the standard insulation material. Alumina offers high thermal conductivity and high electrical resistivity.

Sr. No.	Insulation Material	Max./Operating Temperature (°C)	Feature
2	Hafnia (HfO_2)	2,400°C	Refined high-purity hafnia offers a good electrical resistivity at elevated temperatures. Hafnia's resistivity is comparable to that of beryllium oxide, but hafnia does not present the potential health problems associated with beryllium oxide. Hafnia is therefore replacing beryllium oxide in many applications.
3	Beryllium Oxide (BeO)	2,315°C	It has High electrical resistivity, toxic dust. But Beryllium Oxide needs special handling.
4	Magnesium Oxide (MgO)	1,370°C	Used primarily with compacted sheathed thermocouples,
5	Alumina 610	1,200°C	Good Insulation Properties.

5.2 Thermowell

Thermowells provide protection for temperature probes against unfavorable operating conditions such as corrosive media, physical impact (e.g. clinker in furnaces) and high pressure gas or liquid. Their use also permits quick and easy probe interchanging without the need to “open-up” the process.

It is closed-end reentrant tube designed for insertion of a temperature-sensing element, and provided with means for a pressure-tight attachment to a vessel.

Thermowells are typically constructed of solid drilled-out bar stock and are designed to protect a temperature sensor from flow, high pressure and harsh environments. Thermowells encase and protect temperature sensors from the harmful effects of the processes into which they are immersed without substantially insulating the temperature sensor (thermocouple, RTD, etc.) from the temperature of the process.

Thermowells are hidden in pipes and are rarely seen. Thermowells are permanently placed into pipes, tanks or sumps so that temperature measurement probes can be inserted into the pipe to measure the contents temperature.

5.2.1 Most Common Types of Thermowells

5.2.1(a) According to their connection to process

The most common types of thermowells are:

(1) Threaded

(2) Socket Weld

(3) Flanged Welded

Thermowells are classified according to their connection to a process.

(I) Threaded Thermowell

A threaded Thermowell has threads at its one end and is screwed into the process. Thread can be of tapered or parallel type. Parallel or tapered thread is made for convenient installation into a weld in fitting directly into the process. Such a connection is suitable for smaller diameter well, which are not likely to be changed.

(II) Socket Weld Thermowell

A socket weld Thermowell is welded into a weldalet and a weld in Thermowell is welded directly into the process. Welded connection can be used when the process is not corrosive and routine removal is not required. High integrity is achieved and this technique is suitable for high temperature and pressure.

(III) Flanged Thermowell

A flanged Thermowell has a flange collar which is attached to a mating flange. Flanged connection is preferable if there is a need for more frequent well replacement such as high corrosion rates.

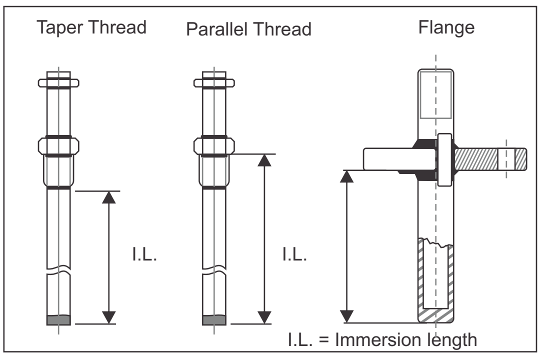
5.2.1(b) According to their production method

Thermowells are also classified according to their production method.

(I) Fabricated Thermowell

(II) Bar-stock thermowell

(III) Van-stone thermowell



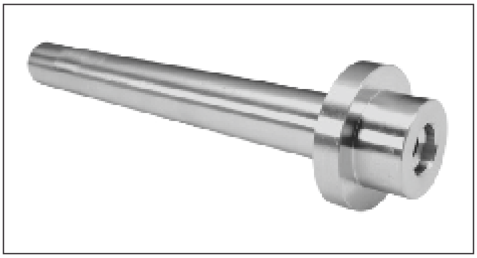
(I) Fabricated Thermowell

Fabricated thermowells are manufactured from tubes which are sealed by a solid welded tip at the process. It means that the stem of thermowell is manufactured from tube and tip is made separately than both these parts are welded by utilizing suitable welding process. The flange is also joined to this assembly by welding process. Fabricated thermowells are generally recommended for low to medium process loads. Connection to the pipe or vessel may be done by means of thread, flange or weld. Standard threads used in fabricated thermowell are NPT, BSP (Pl), BSP (Tr), API & metric thread. The thread size is dependent on the application. Standard sizes range from 1/8” to 2”. For applications where a quick response to changes in temperature is required, fabricated pockets may be fitted with a reduced tip.

(II) Bar Stock Thermowell

Such thermowell bodies are machined and drilled from solid bar stock. This results in a non-welded water tight unit. In this Immersion tip is also made by same material along with stem. In such type of thermowell, no welding process is required for stem and tip production. Flange can be weld according to requirement. Bar-Stock thermowell is also known as “Solid drilled thermowell”. Single piece thermowells are manufactured from a complete element or bar stock. One-piece thermowells are suited to the highest process loads, depending on their design. Thus internationally or in the petrochemical industry, one-piece thermocouples are now used almost exclusively. Connection to the pipe or vessel may be done by means of thread, flange or weld. Standard threads are NPT, BSP (P), BSP (Tr), API & metric tread. The thread size is dependent on the application, but 3/4” and 1” are common.

(III) Van-Stone Themowell



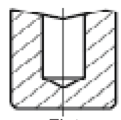
In van stone thermowell, stem, tip and sub part of flange all these three prepared by using single bar or rod material. There is no need of welding for these three parts of thermowell. The flange sub-part serves as a gasket in such type of thermowell. On this sub-part flange is used according to requirement.

5.2.2 Thermowell Tip Profile

Tapered

The outside diameter decreases gradually along the immersion length. Used for high velocity applications.

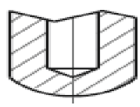
Flat Tip



Flat

It one end has flat surface. Used in low pressure applications or where flow characteristics around the thermowell are not important.

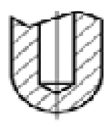
Domed Tip



Domed

Such thermowell has semi-spherical tip at one end of thermowell. Used in higher pressure applications or where flow characteristics around the thermowell are important. This ensures a high degree of mechanical strength without losing the sensitivity or accuracy of the indicator.

Spherical Tip



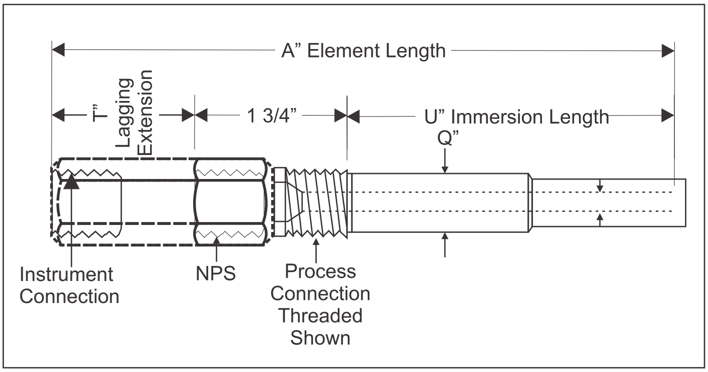
Spherical

For spherical tip, special drill is used with a tip angle of 118ºC for production of thermowell. To achieve a possible uniform wall thickness, the tip is ball shaped or spherical in shape. Used in higher pressure applications or where flow characteristics around the thermowell are important. This ensures a high degree of mechanical strength without losing the sensitivity or accuracy of the indicator.

5.2.3 Basic Construction of Thermowell

Shank Construction

(I) Q Dimension The thickest part of the shank of the well on the hot side of the process connection or flange. It is dependent on the bore size and the process connection size.



(II) Bore Size The inside diameter of thermowell. In other words, the diameter of the internal cylindrical cavity of a thermowell or protection tube Standard bore sizes are 6.5 mm, 8.5 mm.

(III) Immersion ("U") Length The length of a thermowell or protection tube below the mounting threads, flange, bushing, etc. extending into the process area. The "U" length is measured from the bottom of the process connection to the tip of the thermowell.

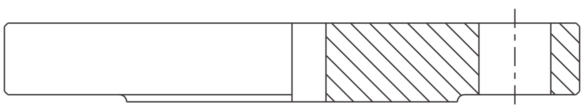
(IV) Lagging Extension ("T") Length The length of a thermowell, in addition to the standard head lengths, required to make the head of the thermowell accessible and this enable the probe to extend through insulation or walls.

(V) Internal Mounting Thread The thread within the thermowell for attaching a temperature device of the union and nipple extension for a thermowell assembly.

5.2.4 Types of Flange Face

(a) Raised Face (RF)

The Raised Face type is the most applied flange type, and is easily to identify. It is referred to as a raised face because the gasket surfaces are raised above the bolting circle face.



(b) Ring-Type Joint (RTJ)

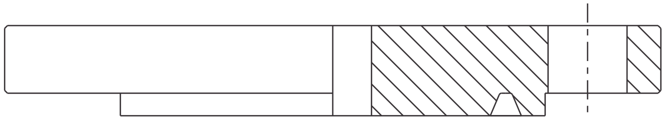
RTJ flanges have grooves cut into their faces which steel ring gaskets. The flanges seal when tightened bolts compress the gasket between the flanges into the grooves, deforming (or Coining) the gasket to make intimate contact inside the grooves, creating a metal to metal seal.

An RTJ flange may have a raised face with a ring groove machined into it. This raised face does not serve as any part of the sealing means. For RTJ flanges that seal with ring gaskets, the raised faces of the connected and tightened flanges may contact each other. In this case the compressed gasket will not bear additional load beyond the bolt tension, vibration and movement cannot further crush the gasket and lessen the connecting tension.

Ring Type Joint gaskets* are metallic sealing rings, suitable for high-pressure and high-temperature applications. They are always applied to special, accompanying flanges which ensure good, reliable sealing with the correct choice of profiles and material.

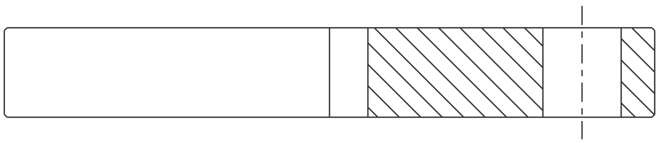
Ring Type Joint gaskets are designed to seal by "initial line contact" or wedging action between the mating flange and the gasket. By applying pressure on the seal interface through bolt force, the "softer" metal of the gasket flows into the micro fine structure of the harder flange material, and creating a very tight and efficient seal.

*** Note: Gasket is a mechanical seal which fills the space between two or more mating surfaces, generally to prevent leakage from or into the joined objects under compression.**



(c) Flat Face (FF)

The flat face (full face) flange has a gasket surface in the same plane as the bolting circle face. Applications using flat face flanges are frequently those in which the mating flange or flanged fitting is made from a casting. Flat face flanges are never to be bolted to a raised face flange.



5.2.5 Welding on Thermowells

Welding is a process of joining two metals by heating the metals to a suitable temperature. It may be done with or without the application of pressure, and with or without filler.

Types

Full Penetration Welding - This type of welding ensures a fully welded interface between the two parts and is generally the strongest joint.

Partial Penetration Welding - This type consists of a partially welded interface with filler metal being laid on the surface of the two metals.

5.2.6 Welding Procedure Specification (WPS) & Procedure Qualification Record (PQR)

A WPS is a document that describes how welding is to be carried out in production. They are recommended for all welding operations and many application codes and standards make them mandatory.

The purpose of the document is to guide welders to the accepted procedures so that repeatable and trusted welding techniques are used. A WPS is developed for each material alloy and for each welding type used.

A WPS is supported by a Procedure Qualification Record (PQR or WPQR). A PQR is a record of a test weld performed and tested (more rigorously) to ensure that the procedure will produce a good weld.

The variables required to be documented are typically such items as:

- welding process used, size, type and classification of filler alloy.
- type and thickness of base material welded.
- type and polarity of welding current, amps and volts recorded.
- travel speed during welding, welding position, type and dimensions of joint design.
- preheating temperature, interpass temperature, post weld heat treatment details, and others.
- In addition to the recording of all the welding variables used during the test, in order to qualify a welding procedure, details of the inspection and test results must also be recorded. These records must show that the inspection and testing has proven that the weld samples have met or exceeded the specified standard requirement.

WPS FILLED FORMAT

TEMPSENS INSTRUMENTS (I) PVT. LTD (UNIT# I)
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E-mail : info@tempsens.com, Web: www.tempsens.com

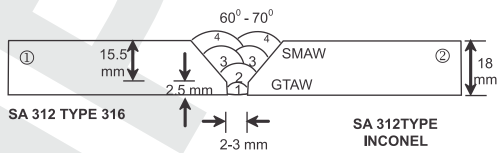
QW–482 SUGGESTED FORMAT FOR WELDING PROCEDURE SPECIFICATIONS (WPS)
(See QW-200.1, Section, IX, ASME Boiler and Pressure Vessel Code)

Company Name :	M/s. Tempsens Instruments	By :			
Welding Procedure Specification No. :	WPS – TIIPL - 0 2	Date :	08.04.2011	Supporting PQR No(s).	PQR-TIIPL-02
Revision No. :	–	Date :	–		
Welding Process (es)	GTAW	Types(s)	Manual		

Joints (QW-402) Groove Design used

Joint Design Single Side full Penetration Groove
Backing = No for GTAW root run only
Backing = Yes for other than root run
Backing Material (Type) = Weld metal only

☑ Metal ☒ Nonfusing Metal
☒ Nonmetallic ☒ Other



Single side full penetration weld joint

BASE METALS (QW-403)

P. No.	8	Group No.	1	to P. No.	45	Group No.	1
Or							
Specification Type and Grade	SA 312 TYPE 316						
to Specification Type and Grade	SB 408 TYPE INCONEL						
Or							
Chem. Analysis and Mech. Prop.	NA						
to Chem. Analysis and Mech. Prop.	NA						
Thickness Range :							
Base Metal : Groove	1.5 MM TO 15MM			Fillet	All		
Other							

FILLER METALS (QW-404)	**GTAW**	
Spec. No. (SFA)	SFA 5.9	
AWS No. (Class)	ER INCONEL	
F. No.	6	
A. No.	8	
Size of Filler Metals	1.6 mm Ø	
Weld Metal	–	
Thickness Range	1.5 MM TO 15MM	
Groove	1.5 MM TO 15MM	
Fillet	All	
Electrode Flux (Class)	NA	
Flux Trade Name	NA	
Consumable Insert	NA	
Other	NA	

TEMPSENS INSTRUMENTS

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QW–482 SUGGESTED FORMAT FOR WELDING PROCEDURE SPECIFICATIONS (WPS)
(See QW-200.1, Section, IX, ASME Boiler and Pressure Vessel Code)

POSITION (QW-405)	
Position(s) of Groove	1G
Weld Progression Up	NA
Position(s) of Fillet	NA

PREHEAT (QW -406)	
Preheat Temperature Minimum	NA
Interpass Temperature Maximum.	150^{0}C
Preheat Maintenance	NA
(Continuous or Special heating, where applicable, should be recorded)	

POST WELD HEAT TREATMENT (QW -407)	
Tempera ture Range	NA
Time Range	NA

GAS (QW-408)	Gas(es)	(Mixture)	Flow Rate
Shielding	Argon	99.99 %	5 - 6 LPM
Trailing	NA	NA	NA
Backing	NA	NA	NA

ELECTRICAL CHARACTERISTIC (QW-409)			
Current (AC or DC)	DC	Polarity	EN (for GTAW)
Amperes (Range)	Refer Table - I	Voltage (Range)	Refer Table - I

(Amps and volts range should be recorded for each electrode size, position, and thickness, etc.
This information may be listed in a tabular form similar to that shown below).

Tungsten Electrode Size and Type	2.4 MM (2% Thoriated)
Mode of Metal Transfer for GMAW	– NA –
Electrode wire feed speed range	– NA –

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QW–482 SUGGESTED FORMAT FOR WELDING PROCEDURE SPECIFICATIONS (WPS)
(See QW-200.1, Section, IX, ASME Boiler and Pressure Vessel Code)

TECHNIQUE (QW-410)	
String or Weave Bead	Weave (Max 4.2mm for 1.6mm filler wire GTAW)
Orifice or Gas Cup Size	10 mm Dia for GTAW
Initial and Interpass Cleaning (Brushing, Grinding, etc.)	Wire Brushing & Gauging
Method of Back Gouging	– NA –
Oscillation	– NA –
Contact Tube to Work Distance	– NA –
Multiple or Single Pass (Per Side)	Multiple
Multiple or Single Electrodes	Single
Travel Speed (Range)	Refer Table – I
Peening	– NA –
Other	– NA –

TABLE – I

Weld Layer (s)	Process	Filler Metal		Current		Voltage Range	Travel Speed Range (mm/min)	Other (e.g., Remarks, Comments, hot wire Addition, Technique, Torch Angle, etc.)
		Class	Dia (mm)	Type & Polarity	Ampere Range			
ROOT	GTAW	ER INCONEL	1.6	DCEN	100 – 140	14 – 20	60	–
RUN	GTAW	ER INCONEL	1.6	DCEN	140 – 180	20 - 28	70	–

○ NA – Not Applicable

5.2.7 Thermowell Special Coating

Different types of coating are carried out in thermowells. Some are as follows: Metal Thermowells with Tungsten Carbide / Ceramic / PTFE / PVDF / PFA Coatings.

Sr. No.	Coating	Thickness	Operating Temperature (°C)	Features
1	Tungsten Carbide Coated	0.5-1.0mm	Below 650°C	Tungsten carbide coating offers effective wear resistance coating, as it offers exceptionally high hardness level (maximum 74 HRC hardness). It is resistance to high temperature and corrosion & high abrasive condition.
2	Teflon Coated	0.5-1.0mm	200°C	Teflon coating provides a dry film lubricant witch provides excellent resistance against corrosion and chemicals.
3	Boron Nitride Coated	0.5mm	900°C	Boron nitride protects surface witch comes in contact with molten metal (specially aluminum). Boron nitride inhabits corrosion and chemical attacks, and provide easier release and longer life.
4	Zirconia Coated	0.5-0.1mm	1800°C	Zirconia coating produces a hard and chemically resistant protective layer suitable for high temperature and corrosion.
5	Alumina Coating	0.5-1.0mm	1200°C	Alumina coating provides a high temperature abrasive protection.
6	Stellite Coating	0.5-1.0mm	1200°C	Stellite coating provides very good abrasion resistance and good chemical corrosion resistance.

5.2.8 Test on Thermowell:

1. Material Test

Chemical- By PMI(Positive Material Identification).

Physical -By Tensile, Elongation, Hardness, Micro & Macro examination, IGC tests.

2. Dimensional Test

The Thermowell must be checked according to specified dimension given in drawing.

3. Hydrostatic Pressure Test

A hydrostatic pressure test is a way in which leaks can be found in pressure vessels such as pipelines and plumbing. The test involves placing water, which is often dyed for visibility, in the thermowell at the required pressure to ensure that it will not leak or be damaged. It is the most common method employed for testing pipes and vessels. Using this test helps maintain safety standards and durability of a vessel over time. Newly manufactured pieces are initially qualified using the hydrostatic test.

4. Dye Penetrant Inspection

Dye penetrant inspection (DPI), also called liquid penetrant inspection (LPI) or penetrant testing (PT), is a widely applied and low-cost inspection method used to locate surface-breaking defects in all non-porous materials (metals, plastics, or ceramics). LPI is used to detect casting, forging and welding surface defects such as hairline cracks, surface porosity, leaks in new products, and fatigue cracks on in-service components.

5. Radiography

Radiographic Testing (RT), or industrial radiography, is a nondestructive testing (NDT) method of inspecting materials for hidden flaws by using the ability of short wavelength electromagnetic radiation (high energy photons) to penetrate various materials. irregularities and flows that can be detected witch includes - cracks, voids, thickness, lack of fusion, lack of penetration, porosity and misalignment .

5.2.9 Selection of Thermowell

Materials the Longevity Factor

The selection of material is the most important factor for thermowell life. The material selected is based on the temperature of the application and the process medium.

1. Connection-The Installation Factor

All threaded well are made by easily welded or brazed materials. Welding and brazing is important for the installation requiring seal. The pipe thread provides mechanical strength, and the weld or braze provides the seal.

Flanged wells (other then van stone type) consist of a bar stocks well which is solidly welded to a top quality flange. Standard construction uses a primary "J" groove weld and a bevel groove clean fillet. This double welded construction eliminates the possibility of crevice corrosion since no open joint are exposed from either inside or outside the installation. Socket weld well are simple to install, simply weld them into place.

2. Insertion Length-The Accuracy Factor

The distance from the tip of the well to the underside of the thread or other connection is defined as the insertion length (designated as "U"). For best accuracy this length should be greater enough to permit the entire temperature sensitive part of element to project into the medium being measured. A properly installed element: in liquid, the element should be immersed up to its sensitive length plus one inch, and in air or gas, the element should be immersed up to its sensitive length plus three inches.

3. Bore Size-The Interchangeability Factor

Almost all installation uses several type of temperature measuring sensor. The selection of a standard bore diameter can produce extreme flexibility within the plant. The same well can accommodate thermocouple, resistance thermometer, and bimetal thermometer.

4. Tapered or Straight Well- The Velocity Rating Factor

Tapered shank provides greater stiffness with same sensitivity. The higher strength to weight ratio give these wells higher natural frequency than the equivalent length straight shank well thus permitting operation at higher fluid velocity.

5.2.10 PTC 19.3 Standard for Thermowell:

The American Society of Mechanical Engineers (ASME) Performance Test Codes (PTC) is used to determine the performance of specific, mechanical equipment, which are designed to meet specified criteria for performance and operability. The results from applying Codes indicate how well the equipment performs its intended function.

The ASME PTC 19.3 is a thermowell stress calculation, which serves as a mathematical proof that the material chosen and the mechanical design will not fail given the effects of the operating conditions. The calculation provides guidance for establishing a comparison between the shedding frequency and the natural frequency of the thermowell.

PTC 19.3- 2010 Standard for Thermocouple

In 1999, it was discovered that thermowells designed to PTC 19.3-1974 in no steam services suffer catastrophic failure. Due to this problem, the committee decided to rewrite the entire standard. The 2010 version includes an evaluation of the forces caused by external pressure and the combination of static and dynamic forces.

ASME PTC 19.3 TW-2010 standards main criteria's for thermowell are as follows:

a.) Criteria for Thermowells

The ASME PTC 19.3 TW-2010 standard applies to thermowells that are:

1. Machined from bar stock.
2. Straight, tapered or step-down shank.
3. Threaded, flanged, van stone or welded process connection.
4. Surface finish of 32 µin. Ra or better.

b.) Not within the Scope of This Standard

1. Thermowells manufactured from pipe.
2. Specially designed surface structures, e.g. knurled, spiral.
3. Thermowells fabricated in piece construction (welding of the shank in sections).
4. Shanks that include flame spray or weld overlays.
5. Use of ball joints, spherical unions or packing glands.
6. Ceramic wells or any non-metallic or exotic metals.

c.) Selection of Thermowell Materials

The selection of thermowell material is usually governed by corrosion resistance, strength requirements, temperature limits and welding compatibility to the process piping in the case of socket and weld-in thermowells. Materials should be certified to meet the requirements of recognized codes (ASTM, ANSI or ASME).

Other materials may be used, providing they conform to published specifications covering chemical, physical and mechanical properties as required by this standard.

d.) Low Fluid Velocities

At low velocities, the risk of thermowell failure is minimal and does not usually require frequency calculations.

If the following criteria are met, the designer may elect to wave calculation requirements.

1. Maximum fluid velocity is less than 2.1 ft/sec. [0.46 M/s].

2. Wall thickness at "A" support diameter minus "b" bore diameter ⩾ 0.376" [9.55 mm].

3. "L" Unsupported length ⩾24" [.61 M]

4. "A" support and "B" tip diameter ⩾ 0.5" [12.7 mm]

5. Thermowell material satisfies "S" maximum allowable working stress ⩾ 69 Mpa.

6. "Sf" fatigue endurance limit, in the high-cycle limit ⩾ 21 Mpa.

7. Thermowell material not subject to stress corrosion or embrittlement.

e.) Frequency Limits

ASME PTC 19.3 TW-2010 has revised the frequency criteria based on limits set by in-line resonance and passage of static cyclic conditions.

In low density gases with a Scruton Number (Nsc) of >2.5 Reynolds Number <105, the in-line resonance is suppressed and therefore the acceptable ratio will be:

$$f s < 0.8 f nc$$

If a thermowell passes cyclic stress conditions for operation at the in-line resonance condition, the acceptable ratio will be:

$$f s < 0.8 f nc$$

If a thermowell fails the cyclic stress condition for operation at the in-line resonance condition, the thermowell natural frequency will be high enough to limit excitation of the in-line resonance. Therefore, the acceptable ratio will be:

$$f s < 0.8 f nc$$

f.) Process Information Required to Run the ASME PTC 19.3-TW-2010 Calculation

This Software is free downloadable from our website link
“*http://tempsens.com/thermowell_calculator.html”.*

Minimum mandatory information required

1. Maximum or operating temperature.

2. Maximum or operating pressure.

3. Fluid (gas or liquid) velocity.

4. Fluid density.

Additional Information if available (recommended)

1. Process Fluid (air, steam, water, etc.).
2. Pipe size and schedule.
3. Fluid flow rate.
4. Fluid viscosity (will use 0.0171 centipoises if not known).
5. Shielded length (flanged Thermowell). if information is available, their will improves stress resistance.

5.3. Thermowell Fitting Accessories

Installing temperature sensor assembles into thermowell or directly into the process requires the use of some kind of brass or stainless steel fitting.

Fitting include various threaded unions, bayonet cap (and adapters) and flange.

Adjustable flange can similarly be used to sensor assembly into the process.

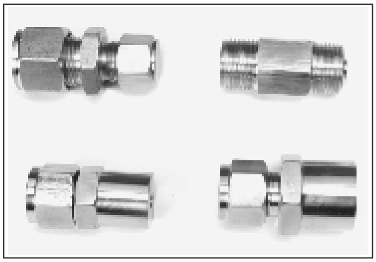
Bayonet caps provide a method of quick fitting into suitable adapters located in the process; this technique is widely used in plastics machinery.

Bushes and hexagon plugs are used when adjustment or removal is a lesser consideration.

The choice of fitting may be dictated by the need for pressure integrity or by physical size constraints. Compression fitting and threaded bushes can be supplied with tapered threads to achieve a pressure-tight connection.

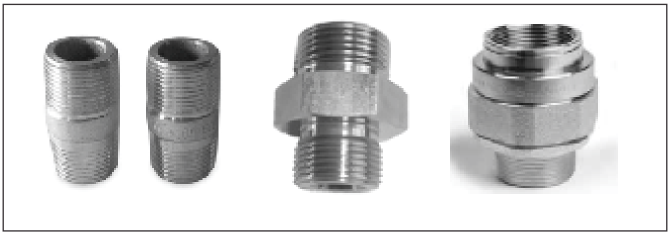
a.) Compression Fitting

Adjustable compression fitting are used directly on probe to achieve the required insertion length in the process and to ensure the proper sheathing of probes into thermowell. Compression fittings for attaching tubing (piping) commonly have ferrules in them. Compression fittings are popular because they do not require soldering, so they are comparatively quick and easy to use.



b.) Nipple Fittings

Nipples are made up with a flange from the same family on each end of a tube section. (Fittings that are manufactured with different flange families on each end are called hybrid adapters.) Straight nipples are manufactured with the same size flange on each end of straight section of tubing. Reducer nipples have different size flanges (from the same family) on each end.



The three piece unions have to be used in hazardous areas, for the junction between conduits pipes and boxes or various appliances. The unions are made up of three independent pieces that can be screwed up by rotating the same pieces among them.

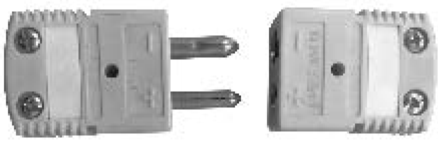
5.4. Terminations

Metallic Plugs and Socket Connections

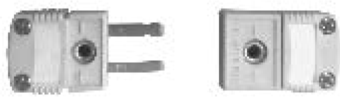
The link between the thermoelectric wires of the thermocouple and those of the extension cable is made by means of non - compensated male and female connectors. The metallic body and casing of these connectors ensure the screening continuity as well as good temperature.

Standard & Miniature Thermocouple Connectors

Standard & Miniature connectors are ideal for connecting thermocouple sensors and extension or compensating cable to each other. The pins are polarized to avoid an incorrect connection and the connector body is additionally marked for polarity. These connectors have color coding according to special standard like: ANSI, IEC etc.



Standard Connector



Miniature Connector

Lemo Connector

6
Extension Leads & Compensating Cable

6.1 Introduction

It is often desirable to connect a thermocouple probe, as a part of a very long circuit from the sensor itself to a remote reference unit and/or measuring instrument. Yet, we would avoid the expense of high specification thermocouple cable on a long run. Connecting cheaper cable would be ideal but we need to do so without having to take particular care that temperature where the connection is made is known and taken in to account.

When connecting thermocouples to instruments, it is essential that a cable is used, which has the same emf output as the thermocouple; otherwise spurious emf is generated at these junctions. The best solution is to use the same material as the thermocouple (extension cable).

A cheaper alternative is to use compensating cables, the alloys of which are different from those of the thermocouple but have the same output over a limited temperature range.

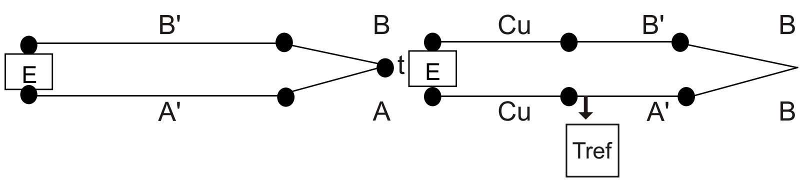
Compensating and extension grades of wire are supplied in the bright-annealed condition.

For this to be possible, the thermo electrics properties of the additional conductor must not differ too much from those of the thermocouple itself.

Extension and compensating cable provide convenient, economic solution-each with its pros and cons.

Extension cable uses wire of nominally the same conductor as the thermocouple itself, which thus inherently possess similar thermo power characteristics, and with no connection problems.

Miss-match error arising from high connecting box temperature is likely to be relatively small. These cable are less costly then thermocouple wire, although not cheap, and are usually produced in a convenient form for carrying over long distance typically as flexible wiring or multi-core cables. They are recommended for best accuracy.



Connection of extension or compensating cable

Compensating cables, on the other hand are less precise, but cheaper. They harness quite different relatively low cost alloy conductor materials, whose net thermocouple in question, but which not them as faithfully as do extension cable. Thus, the combination develops similar output as those of the thermocouple, but the operating temperature range has to be restricted to keep miss-match error acceptably small.

6.2 Insulation

Insulation refers to the layer of plastic, polymer or high temperature compound that is applied directly over the conductor. Tempsens provide variety of insulation along with wide temperature range from -260°C to 1200 °C. Most of the insulation materials are also used for sheathing purpose.

Insulation material are choose according to their electrical, Mechanical and high temperature characteristics.

Sheathing refers to the outer most layer of the plastic, polymer or high temperature compound that is applied to a cable. The outer sheath (or jacket as it is also commonly known) is there to provide mechanical protection for the insulated cores & other component inside the cable.

Tempsens basically categorized four types of insulating material

Thermoplastic Compound

6.2.1 PVC (Poly vinyl chloride) Temp. Range from-40°C to 85°C

Generally self extinguishing, it's used for insulation and sheath. It turns into soft over 90 °C,at low temperature (-40 °C) it turns brittle. It has good mechanical properties, water resistant, flame retardant, chemical & oil resistant & very good resistance to abrasion.

Elastomeric Compound. PVC material have various type of Grade i.e. HR PVC, FR PVC, FRLS PVC.

Properties	Standard	PVC (General Purpose PVC)	FR PVC (Flame Retardant PVC)	FRLS PVC (Flame Retardant) & low smoke PVC	HR PVC (Heat Resistant PVC)
Specific gravity	ASTM-D-792	1.44 +/- 0.03	1.60 +/- 0.03	1.47 +/- 0.03	1.32 +/- 0.03
Hardness (Shore A)	ASTM D2240	79 +/- 3	93 +/- 3	91 +/- 3	85 +/- 3
Tensile Strength (Min.) Mpa	IS 10810	14 Mpa	12.5 Mpa	17 Mpa	20 Mpa
Elongation % (min)	IS 10810	280%	150%	180%	225%
Volume	80 Min.	120 Min.	140 Min.	180%	225%
Resistivity (ohm.cm)	IS 10810	5 X 10 ^13	10 X 10 ^13	8 X 10 ^13	2.6 X 10 ^13
Thermal stability at 200°C (min)	IS 5831	80 Min.	120 Min.	140 Min.	100 Min.

6.2.2 PE (Polyethylene) Temp. Range from -10°C to 70°C

It is used for only insulation purpose. It provide a very good insulating & dielectric properties, having excellent insulation resistance (> 5000 Mohms/Km).Its operating temperature is from -10 °C to 70 °C and it is suitable for application where good resistance to water absorption and to abrasion is required.

6.2.3 Silicon Insulation Temp. Range from -50°C to 200°C

Silicon insulation has superior heat resistance, cold resistance, excellent resistance and flexibility. Mechanical strength is enhanced by glass braiding having excellent electrical properties suit for high voltage. Silicon rubber is excellent chemical resistance to acids, oil & liquid fuels. These are flame retardant not propagating flames when exposed to fire action.

When silicon insulated cable is attacked by fire, sheath and Insulation crystallize maintaining their electrical properties for enough time to allow safety measure operations.

Properties	Unit	Value
Hardness	Shore A	65 - 70
Density	Gm/Cm3	1.18 - 1.50
Elongation at break	%	350 - 500
Tensile Strength	Mpa	5.5 - 9.5
Tear resistance	N/mm	20 - 45

6.2.4 XLPE Insulation Temp. Range from -50°C to 105°C

Known as Cross linked Polyethylene Insulation, Generally used for insulation of medium & high voltage cables. Its operating temperature range is -50 °C to 105 °C. It is used only for as insulating purpose.

6.2.5 EPR Insulation Temp. Range from-40°C to 90°C

Generally used for insulation of low voltage cables and instrument cables. Its operating temperature range is from -40 °C to 90°C.

6.2.6 PEEK Insulation Temp. Range up to 250°C

Polyetheretherketone (PEEK) is considered one of the highest performance plastics today. Polyetheretherketone, PEEK, is a semi-crystalline high temperature thermoplastic insulation. PEEK wire has a durability and resistance to harsh environments that makes it extremely useful in the down hole and deep drilling context for the oil industry. PEEK wire is also used in the energy production sector, including in the nuclear industry, due to its superior resistance to radiation. PEEK can be used continuously to 250°C and in hot water or steam without permanent loss in physical properties.

Features

- ✓ Excellent Resistance to Radiation.
- ✓ Superior high temperature performance
- ✓ Improved compressive strength
- ✓ Good electrical properties
- ✓ Excellent hydrolysis resistance
  - Excellent chemical resistance
  - Very low moisture absorption
  - Inherently good wear and abrasion resistance
  - Unaffected by continuous exposure to hot water or steam

Fluoro - Polymers Compound

6.2.7 PTFE Insulation Temp. Range from-267°C to 260°C

PTFE (Poly tetra fluoroethylene) insulation is used in a wide variety of high temperature applications as gas turbine and high voltage gas ignition wires. Due to its thin wall properties, PTFE is used in aerospace & defense and even in vaccum.It temperature range is from -267 to 260°C.

6.2.8 PFA Insulation Temp. Range from -260°C to 260°C

PFA (Per Fluoro Alkoxy) is used for many high temperature applications such as gas turbines. It has almost same properties like PTFE insulation. PFA has the excellent electrical and mechanical performance of PTFE with the added advantage of being easily and conventionally extruded. Its temperature range is from -260°C to 260°C.

6.2.9 ETFE Insulation Temp. Range from -185°C to 150°C

ETFE (Ethylene Propylene Fluoro Ethylene) Insulation is a tough material with excellent tear strength, good tensile strength, outstanding mechanical properties. ETFE has a broad and useful temperature range and retains remarkable toughness at very low temperatures. Its used in extensively in both military and industrial applications. Its temperature range is from -185°C to 150°C.

6.2.10 MFA Insulation Temp. Range from-200°C to 250°C

MFA insulation is also a Fluoro Polymer compound. Its temperature range is up to -200°C to 250°C. It is also have very good dielectric Constant & have excellent resistance to oil, UV rays, chemicals & moisture. It's widely used in high temperature applications, Military and Industrial applications.

Properties	ASTM Standard	PTFE	FEP	PFA	ETFE
Applying Process		Wrapped	Extruded	Extruded	Extruded
Specific Gravity	D792	2.15	2.15	2.15	1.76
Tensile Str.(Mpa)	D1457	14	12.5	17	20
Elongation %(min)	D1457	280	150	180	225
Hardness (HB)	D2240	50-65	56	60	72
Melting Point	327 °C	327 °C	260 °C	306 °C	267 °C
Dielectric Strength/umm)	D149	18	53	80	79
Volume Resistivity (ohm.cm)	D257	>10^18	>10^18	>10^18	>10^18
Temperature Range	JSS 51034	-267 to 260	-200 to 200 °C	-260 to 260 °C	-185 to 150 °C

High Temperature Insulation

6.2.11 Fiber Glass Insulation Temp. Range from -73°C to 600°C

is used for high temperature application its temperature range is from -73°C to 600°C. It has excellent abrasion resistance, excellent dielectric Properties, very good flame retardant and high temperature resistance characteristics. Due to these all characteristic this is widely used in Industrial application like Glass, Steel and Aluminum Plant. It is also used in heat treatment industries.

6.2.12 Ceramic Fiber Insulation Temp. Range from -72°C to 800°C

It has higher temperature range than Fiber glass. Its working temperature is up to 800°C.It has excellent flame retardant & Heat Resistant properties. Widely used in industrial application like Glass, Steel, and Aluminum Plants. Also used in the heat treating industry, furnace surveys and temperature sensors.

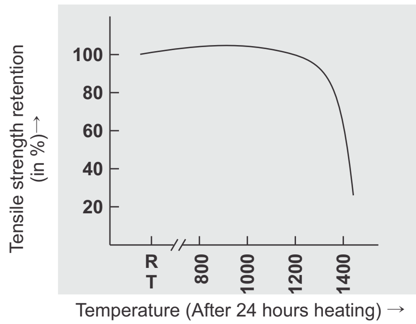
6.2.13 Alumina Fiber Temp. Range from -73°C to 1200°C

Alumina Fiber has highest temperature withstanding range up to 1200°C. It has Excellent Flame retardant & Heat resists properties. Continuous filament Alumina Fiber adopted in conductors insulation and cables jacketing withstands very high temperatures maintaining significant strength and flexibility up to 1200°C for long periods. They present also good chemical resistance.

Alumina Fiber Insulated Cables are useful in application where mineral insulated thermocouple cables are not suitable because of their low flexibility.

Typical Physical Properties (Type F)

1. Colour	White
2. Fiber form	Continuous
3. Filament diameter	7 microns
4. Chemical composition	Al_2O_3 (72%) + SiO_2 (28%)
5. Crystal type	$A_{12}O_3$
6. Density	2.9 g/cm_2
7. Tensile strength	200 Kgs/mm_2
8. Tensile modulus	17,000 Kgs/mm_2
9. Thermal resistance Up to 1,250°C as per the tensile strength retention percentage Vs increasing temperature curve show below :	



6.2.14 Polymide Insulation Temp. Range from -267°C to 310°C

Polymide tape are strong, amber colored, plastic films showing excellent physical, chemical & electrical properties at an extremely wide temperature range. These films don't melt and are fire resistant as they have the highest flammability rating. Its working temperature range is from -267°C to 310°C.

Polymide film doe not soften at elevated temperatures, thus the film provides an excellent release surface at elevated temperatures.

Property	1 mil	2 mil	3 mil	5 mil	Test method
Ultimate Tensile Strength at 73°F, Mpa	231	231	231	231	ASTM D-882-91, Method A*
Ultimate Tensile Strength at 392°F, Mp	139	139	139	139	ASTM D-882-91, Method A*
Ultimate Elongation at 73°F, %	72	82	82	82	ASTM D-882-91, Method A
Ultimate Elongation at 392°F, %	83	83	83	83	ASTM D-882-91, Method A
Density, g/cc	1.42	1.42	1.42	1.42	ASTM D-1505-90
Tensile Modulus at 73°F, GPa	2.5	2.5	2.5	2.5	ASTM D-882-91, Method A
Tensile Modulus at 392°F, Gpa	2	2	2	2	ASTM D-882-91, Method A

6.2.15 Mica

Mica tape is generally as intermediate tape for fire resistance purpose. It has excellent fire resistance, Flame retardant & Heat resistance properties.

6.2.16 Asbestos

The main reasons for the use of asbestos are its fire and heat resistance, electrical insulation properties, acid resistance, and durability. Electrical insulation is also used to protect the surfaces of conductors from such adverse conditions as moisture and chemicals, and to fill spaces where corona discharge is liable to occur.

6.3 Thermocouple Wire Tolerances

The figure shown in the tables are those appropriate to the measuring junction temperature in the final column. In most cases the error expressed in degrees celcius will be larger at lower thermocouple junction temperatures.

Cable	Tolerance Class		Cable Temp. Range	Measuring Junction Temperature
	Class 1	Class 2		
JX	±85µV (±1.5°C)	±140µV (±2.5°C)	-25°C to +200°C	500°C
TX	±30µV (±0.5°C)	±60µV (±1.0°C)	-25°C to +100°C	300°C
EX	±120µV (±1.5°C)	±200µV (±2.5°C)	-25°C to +200°C	500°C
KX	±60µV (±1.5°C)	±100µV (±2.5°C)	-25°C to +200°C	900°C
KCA	–	±100µV (±2.5°C)	-0°C to +150°C	900°C
KCB	–	±100µV (±2.5°C)	-0°C to +100°C	900°C
NX	±60µV (±1.5°C)	±100µV (±2.5°C)	-25°C to +200°C	900°C
NC	–	±100µV (±2.5°C)	-0°C to +150°C	900°C
RCA	–	±30µV (±2.5°C)	-0°C to +100°C	1000°C
RCB	–	±60µV (±5.0°C)	-0°C to +200°C	1000°C
SCA	–	±30µV (±2.5°C)	-0°C to +100°C	1000°C
SCB	–	±60µV (±5.0°C)	-0°C to +200°C	1000°C

NOTE : Identification as to whether a thermocouple cable type is extension or compensating is indicated in the example which follows; however, please note that a letter A or B after the C for Compensating refers to the Cable Temperature Range in accordance with the table of Tolerance Values set out in this standard.

K X 1 = K EXTENSION CLASS 1

K CA 2 = K COMPENSATION CLASS 2, 0º to 150°

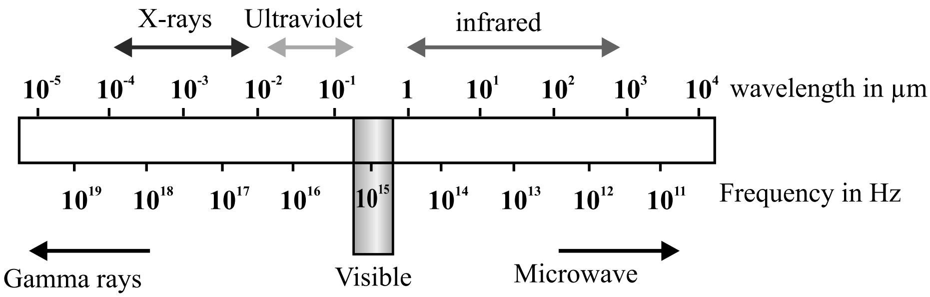
1. Cable temperature range may be restricted to figure lower then those shown in the table because of temperature limitation imposed by the insulant.

2. A cable comprising two copper conductors may be used with type B thermocouple .The expected maximum additional deviation within the cable temperature range 0ºC to 100ºC is 40µV. The equivalent in temperature is 3.5°C when the measuring junction of the thermocouple is at 1400°C.

7
Pyrometer Fundamental and Infrared Thermography

7.1 Basic Concepts

What we see with our eyes is only the small part (visible region) of a broad spectrum of electromagnetic radiation. On the immediate high energy side of the visible spectrum lies the ultraviolet, and on the low energy side is the infrared (IR) (see Figure). This invisible portion of light carries various supplementary informations.



Electromagnetic spectrum

The IR region can be divided into three different categories: near-IR (NIR/Short wave), mid-IR radiation (MIR/Medium wave) and far-IR radiation (FIR / Long wave). Also, this region is responsible for the heating effect of the sun. Understanding the physical basics like blackbody, Planck, Stefan, Boltzmann, Wien and Kirchhoff laws, etc. is crucial before proceeding to the next section.

Table :1

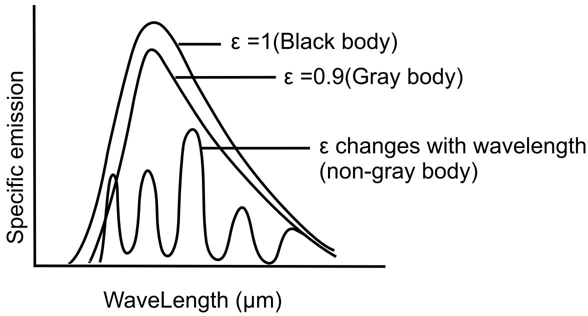
Regions	Wavelength (µm)
Near Infrared (NIR)	0.78 - 3
Mid Infrared (MIR)	3 - 50
Far Infrared (FIR)	50 - 1000

7.1.1 Black Body

A black body is a hypothetical object that absorbs the entire radiation incident upon it. Such body doesn't reflect any radiation and appears perfectly black. The perfect black body is the most efficient thermal absorber and emitter because any object at thermal equilibrium will emit the same amount of light as it absorbs at every wavelength. The radiation spectrum of a black body is determined only by the temperature and not by the properties, material, and structure. These features, as an ideal source to emit or absorb radiation, make the black body valuable for many applications. For an ideal black body absorbtivity and emissivity is one.

7.1.2 Gray Body

The body which emits less thermal radiation than a perfect blackbody or its surface emissivity (ε) is less than one but is constant over all frequencies. It's a useful approximation to some real world materials over some frequency ranges. The spectral emission of gray body is shown in Figure.



Specific Emission of Gray body

7.1.3 Black Body to real objects

A perfect blackbody is only a physical abstraction which does not exist in real world. Each body radiates electromagnetic radiation at a temperature above zero (-273.15°C = 0 K). This radiation is nothing but the body's thermal energy which is being converted into electromagnetic energy and therefore termed as thermal radiation. Real materials show slightly different behaviour as compared to an ideal black body. The radiative property of the real objects always deviates from those of an ideal blackbody. The radiation incident on the real body may undergo following physical phenomenon like reflection, absorption and transmission (permeability) (see Figure).

(a) Absorptivity (α)

The fraction of the irradiation absorbed by a surface is called the absorptivity of a material. It can be characterized by both a directional and spectral distribution. It is understood that surfaces may exhibit selective absorption with respect to wavelength and direction of the incident radiation. However, for most engineering applications, it is desirable to work with surface properties that represent directional averages.

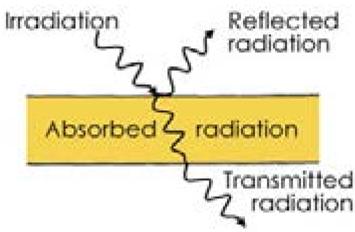


Figure : Annihilation of radiation in real type

(b) Reflectivity (ρ)

The reflectivity of a surface describes the fraction of incident radiation reflected by a surface. If the intensity of the reflected radiation is independent of the direction of the incident radiation and the direction of the reflected radiation, the surface is said to be diffuse emitter. In contrast, if the incident angle is equivalent to the reflected angle, the surface is a specular reflector. Although no surface is perfectly diffuse or specular, specular behavior can be approximated by polished or mirror-like surfaces. Diffuse behavior is closely approximated by rough surfaces and is likely to be encountered in industrial applications.

(c) Transmissivity (τ)

The remaining part of the radiation is transmitted out and the amount of radiation transmitted through a surface is transmissivity. This process too may be selective depending on the nature of the material and the incident radiation.

(d) Emissivity (ε)

Emissivity is the ratio of energy radiated from an object to the exterior and energy radiate from blackbody. The emissivity varies with the surface condition of the object and also with temperature variation and wavelength. If this value is not accurate, then the true temperature cannot be measured. In other words, a variation or change in emissivity will cause a change in the indications.

By the Kirchhoff's law of thermal radiation "At thermal equilibrium, the emissivity (ε) of a body (or surface) equals its absorptivity (α)". So, for a perfect black body, ε is 1 while any real object would have ε less than 1. Also the transmissivity (τ) and reflectivity (ρ) is zero. The sum of absorptivity, reflectivity and transmissivity is always 1.

$$\alpha + \rho + \tau = 1.$$

By the emissivity factor materials can be categorized as:

- Metals
- Non-metals
- Transparent material

7.2 Radiation Principles Governing the Black Body

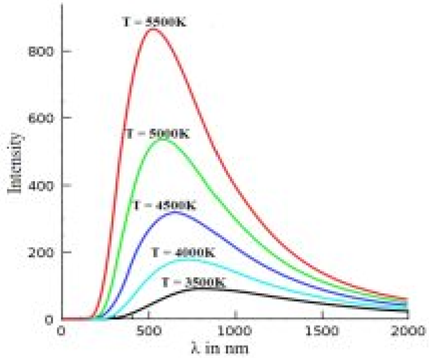
The average or bulk properties of electromagnetic radiation interacting with matter are systematized in a simple set of rules called radiation laws. These laws are applied when the radiating body is a blackbody radiator. Usually, blackbody conditions apply when the body (radiator) has very weak interaction with the surrounding environment and the state of equilibrium is considered. Some of these laws are discussed below:

Planck's law : Planck's law states that the intensity of electromagnetic radiation emitted by a blackbody is a function of frequency (or wavelength). Black body will radiate energy at all frequencies. The Planck's law gives a distribution that peaks at a certain wavelength, the peak shifts to shorter wavelengths for higher temperatures, and the area under the curve raise rapidly with increasing temperature (see Figure).

Wien's displacement and Stefan' Boltzmann law : Wien's displacement law states that the wavelength at which the blackbody emission spectrum varies inversely with the blackbody's temperature or we can say hotter an object is, the shorter the wavelength at which it will emit most of the radiation. Stefan' Boltzmann law states that the total energy radiated per unit surface area of a black body per unit time is inversely proportional to the fourth power of the temperature of the black body.

The Wien law provides the wavelength of the peak of the radiation distribution, whereas the Stefan-Boltzmann law gives the total energy emitted by the blackbody at all wavelengths (i.e., the area under the curve of Planck Law (see Figure)

Also, the Wien law gives explanation to the peak shift to shorter wavelengths with increase in temperature, whilst the Stefan-Boltzmann law explains the growth in the height of the curve with increase in temperature. Both these radiation law can be derived from the Plank's law.



Blackbody spectrum

7.3 Pyrometry

A Pyrometer is a non-Contacting device that intercepts and measures thermal radiation. Without making any contact with the radiating body and the process is known as pyrometry. This device is useful for determining the temperature of an object's surface.

Pyrometer is derived from the greek root 'pyro' which means fire. The term pyrometer means a device capable of measuring temperature of objects above incandescence. Early pyrometers (Filament Pyrometer 1917) were restricted to visual measuring method only (i.e., the object becomes red hot, it starts emitting radiation). So, only high temperature measurement is possible with early pyrometers. But now days such pyrometers are also available that can measure temperatures far below the freezing point from a distance and without making contact with the object to be measured.

Temperature is the most frequently measured physical quantity which predicts the condition of a product or part of apparatus, both in manufacturing and in quality control.

Pyrometer strictly works on the principles of black body radiation. Here emissivity of the target plays an important role, as it govern how bright the target appears to the pyrometer. Due to its high accuracy, speed, economy and specific advantages, it is widely being used as a standard procedure in many industrial applications.

There are some critical considerations which have to be included for any infrared pyrometer like emissivity field of view (size of the target and distance), spectral response and temperature range and mounting. Some of the advantages of non-contact pyrometry are discussed below:

- It records temperature within fractions of seconds (fast response time).
- It does not influence the temperature and material of the target.
- Requires less maintenance and hence the longer life time.
- It can measure the temperature of the moving object.
- Measurements can be taken for hazardous or physically inaccessible object(e.g. high-voltage parts and the great measurement distance).

- As it not in direct contact with target so high temperature can be measured.
- Being non-contact techniques, it will not tamper the target mechanically.

7.4 Choosing the Spectral Range

As discussed earlier, emission coefficient plays a major role for temperature measurement by pyrometers. So it is mandatory to establish accurate emission coefficient for a given material or target.

Metals

The emissivity of metal strongly gets influenced by the wavelength and temperature. For lustrous (smooth) metal surfaces, emissivity is high at short wavelengths and decreases with increasing wavelengths. Moreover wear and tear, oxidation or soiling, rust, etc may also affect the emissivity of metals. So, it is essential to select an instrument which measures the infrared radiation at a particular wavelength and within a particular temperature range at which the metals have the highest possible emissivity.

The optimal wavelength for high temperatures in the case of metals is, at around 0.8 to 1.0 μm, at the limit to the visible range. Wavelengths of 1.6, 2.2, and 3.9 μm are also possible. Good results can be achieved using ratio pyrometers in cases (e.g. heating processes) where measurement is to take place across a relatively wide temperature range and the emissivity changes with the temperature.

Plastics

The transmittance of a plastic altered with the wavelength and thickness of the material. So optimal temperature measurement is accomplished with the wavelengths where the transmittance is almost zero. Polyethylene, polypropylene, nylon and polystyrene are some of the plastics which are non-transmissive at 3.43μm while polyester, polyurethane, Teflon FEP, and polyamide non-transmissive at 7.9μm. The optimal spectral bandwidth for measurement can be determined by the manufacture of the infrared device.

Glass

For temperature measurement of the glass with an infrared thermometer, reflectance together with the transmittance has to be considered. Only a careful selection of the wavelength facilitates measurements of the glass surface as well as of the deeper layers of the glass. For measuring deeper layers wavelengths of 1.0μm, 2.2μm or 3.9μm are appropriate while for surface measurements 5μm is recommended. At low temperatures, 8.14μm should be used with the emissivity set to 0.85, to compensate for reflectance. As glass is a bad heat conductor can change its surface temperature quickly, so a thermometer with short response time is recommended.

Bright Flames

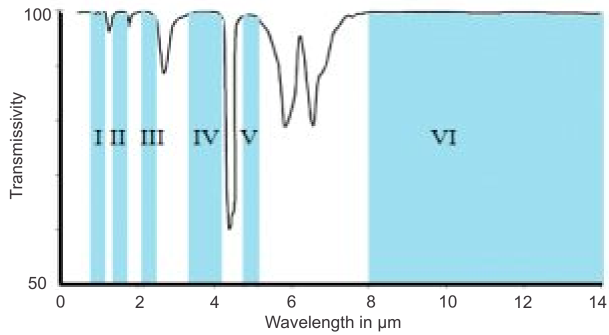
To measure the temperature of flames is really a tough job. For exact measurement of temperature of flames, only the radiation coming from the glowing soot or other burning particles should reach the pyrometer. This can be done by flame pyrometers by adjusting the soot factor "n" on the pyrometer.

Non-Luminous Flames

To measure the temperature of non-luminous flames (e.g. gas burners) spectral pyrometers can be used. This pyrometer measure the radiation of hot carbon dioxide in a very narrow spectral area (4.5 & 4.65 μm).

Ambient Conditions

The transmission behavior of the transmission path (usually the ambient air) should also be considered before setting any IR thermometer (spectral radiation pyrometer). There are certain components in the atmosphere (like vapor, carbon dioxide, etc.) which absorb infrared radiations at particular wavelengths due to which transmission is attenuated. So for accurate temperature measurements, these absorption media should be taken in account. There are 'windows' in the infrared spectrum which do not contain these absorption bands (see Figure). Typical measuring windows are 1.1-1.7 μm, 2 - 2.5 μm, 3.5 μm and 8.14 μm. So the infrared measuring device has to be designed with proper atmospheric correction filters. In Table 2, the various atmospheric windows are listed for different compounds.



Atmospheric windows and transmission of air

Table : 2

Type of Detector (Material)	Window
Silicon	I
Germanium Indium-Gallium-Arsenide	II
Lead Sulphide	III
Lead selenide Thermopile Pyroelectric Detector	IV
Thermopile Pyroelectric Detector	V
Thermopile Pyroelectric Detector	VI

7.5 Methods for Determining the Emissivity

There are several ways to determine the emissivity of the material to ensure accurate temperature measurements, some of which are discussed below:

1. The temperature of the object is first determined (measured) with a contact thermometer. Then aim the pyrometer to the object. Now adjust the emissivity until the same temperature is achieved in both the devices. This method can only be applied for sufficiently large and accessible objects.

2. Coat the material or the portion of it with a special coating whose emissivity approximately equals to 1, accurately known and is stable up to the temperature to be measured. When pyrometer is aimed to the object it first measures the temperature of the coated surface and then it measures the un coated part of the surface. Simultaneously, adjust the emissivity so as to force the indicator to display the correct temperature.

3. For measuring high temperatures, a hole can be drilled (drilling depth should be ≤ 1/3) to the object which acts a blackbody with emissivity of 1.0. The temperature of the drill hole is measured first, then the pyrometer measure surface temperature. Now emissivity is so adjusted such that the correct temperature of the material is displayed on the indicator.

4. The emissivity of a sample object can be determined by spectrometer analysis.

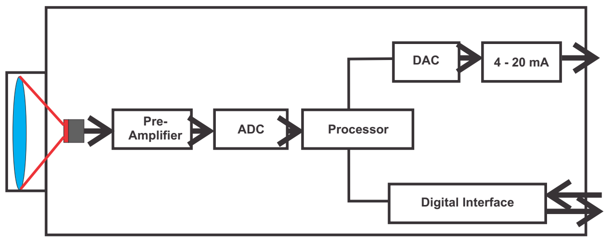
5. Standardized emissivity values for most materials are available. These can be entered into the instrument to estimate the material's emissivity value.

7.6 Basic Design, Construction and Operation of Pyrometer

This section describes the basic construction of a pyrometer and its functioning. Pyrometer is any temperature-measuring device that includes a sensor and a read out. An optical system gathers the visible and infrared energy from an object and focuses it to the detector. The detector receives the photon energy from the optical system and converts.

it to an electric signal to drive a temperature display or control unit. The block diagram of infrared thermometer is shown in Figure.

Infrared thermometers have various configurations and designs, which differ in optics, electronics, technology, size and housing. However, the method of signal processing is same (i.e., it always starts with an infrared signal and ends with an electronic temperature output signal). The working mechanism of the pyrometer is shown in the flow chart (see Figure)



Block Diagram of Infrared thermometer

7.6.1 Optical system, protection windows, spot size and measuring distance

The detector and optical system are the major components in the pyrometer. So, they should be carefully selected to yield the optimum compromise based upon the conflicting parameters of price, accuracy, speed of response, and usable temperature range.

Optical system and protection windows

An optical system mostly consists of windows, lenses and filters. A lens system can be used for particular wavelength ranges due to their material wavelength ranges. Usually for fixed focus optical instruments mirror system is used while for varying the focus instrument requires moving parts, which is less complicated in a lens system. So lens system is preferably used.

The characteristics (transmission values) of the lens, filters and protection window material should be in accordance with spectral sensitivity of the sensor. At high temperatures quartz glass is commonly used. At low temperatures (in the range 8.14μm) special IR transmissive materials (i.e., Ge and ZnSe) are required.

With the help of filters the transmission properties can be modified so that the unwanted wavelengths can be prevented from reaching the detector. They are placed in front of the detectors.

Spot size and measuring distance

The optics of a pyrometer transmits the image of a section of the target area of the measured surface to the detector. The common law of optics used in photography is that as the distance between the camera and the target increases area covered will also increases accordingly. So the distance between the camera and the target should be considered explicitly. The dimensions of the measured object determine the required spot size of the pyrometer. So the target size should be larger than the detector spot (spot size).The distance ratio describes the size of the measuring spot at a certain distance. Also, the ratio of the distance of the measuring device from the target, and the diameter of the spot (D:S) describes the optical resolution. Better the optical resolution of the pyrometer smaller the target can be. To avoid errors in the measurements, the spot size should completely fill the object otherwise the sensor will read the other temperature radiation from the background.

Sighting techniques

There are several techniques for the adjustment of pyrometer which assist in capturing precise radiated temperature from the target. Some of them are described below:

Trough the lens sighting technique

In this technique, user looks at the object in the similar way as he looks through the camera. The centre of the viewing area is indicated by some marks which is the target area. Here user is in direct contact with radiations, so some filters are used for the protection of eyes.

Pilot lights/Laser-pointer

LED, or laser can be used as Pilot lights. The light beam facilitates the user to aim at the measuring spot more quickly and precisely, and hence accurate temperature can be measured in darkness.

7.6.2 Detector

Detector play the vital role in any pyrometer. They are the radiation receivers which converts the received infrared radiation into electrical signals. These electrical signals are converted then displayed as temperature values by the electronic system. Detectors may be classified into two different categories viz. thermal detector and quantum detectors. the behavior of thermal detector is similar to any thermocouple. When the photons interact with the sensitive element in the thermal detectors the temperature of this element get varied which in turn modifiers the property of detector. This modification is then electrically analysed which similar to the voltage generated in any thermocouple Quantum detectors works on the principle of photoelectric effect. They interact directly with the impacting photons. So they are also known as photodiodes. Quantum detectors are faster than thermal detectors. The performance of detector is strongly affected by the variation of ambient temperature. This ambient drift should be compensated for high accuracy measurements.

7.6.3 Electronics

The function of the electronics of the infrared thermometer is to amplify, regular, linearise and convert the signal from the detector to electric signal (mV or mA) which is proportional temperature. The output of the pyrometer can be viewed with analog and digital devices.

- **Target Emissivity :** It can set the emissivity of the target.
- **Peak Picker :** It locates the maximum temperature of the target temperature value from specified number of stored real temperature in the sensor memory. Once the peak temperature is determined, its value will be transmitted constantly even at out of range condition till a new picker process finishes.
- **Switch Off Level :** Ratio pyrometer shows true temperature even when the target is partially visible. The user can adjust this value, so when temperature of object is below this limit, the pyrometer will stop temperature measurement.
- **Response Time :** This function is used to set the response time of the pyrometer. It is adjustable from 20 ms to 10 seconds.
- **Record View :** This option provides data logging. The temperature and Emissivity read by both the pyrometer with time and date is displayed.
- **Spot Size Calculation :** It calculates the spot size or Actual Working Distance of the pyrometer. This option in the software is capable of calculating the spot size for real working distance corresponding to the value of Actual Working Distance.
- **Analog Scale :** User can select the sub range with in the basic range of pyrometer. Analog output will automatically adjust to the selected range.
- **Change Sensor Type :**This parameter display pyrometer sensor type and user can also change two color sensors to single and vice versa within the same software.

7.6.4 Calibration :

To achieve a reasonable level of accuracy, new pyrometer should be properly calibrated. Initial calibration is likely to be performed by the manufacturing. but for the most qualitative measurements periodic recalibration is required. There are three different methods of calibration which are :

Method 1. **-** A commercial blackbody simulator which is an isothermally heated cavity having very small aperture can be used as calibrator, The depth of this cavity should be at least six times as long as its diameter and the temperature of this cavity is controlled by a temperature controller (Using a thermocouple probe). The emissivity of a cavity type blackbody source is usually 0.98 or higher which makes them ideal for exact calibration tasks.

Method 2. **-** Calibrated tungsten filament lamps are commonly used as reference at higher temperatures.

Method 3. **-** third option is to use a reference pyrometer whose calibration is known to be accurate. Adjust the output of the pyrometer until it matches the value of reference pyrometer.

7.7 Sources of Interference

Other than the emissivity factor there are several other interference source which hinder the accuracy of measurement. Some of these factor are discussed below:

- Additional heat source present in the surroundng of the measuring object (e.g. measuring temperature of metals in industrial ovens, where the oven walls are hotter than the measuring object) Strongly influence the measurement may get affected.
- If the target is transparent and there is some hot body behind it then the target will let the additional

heat pass through modifying the original temperature.

- The presence if dust, water vapor, smoke and window also reduce the strength of the infrared radiations.

7.8 Pyrometer Types

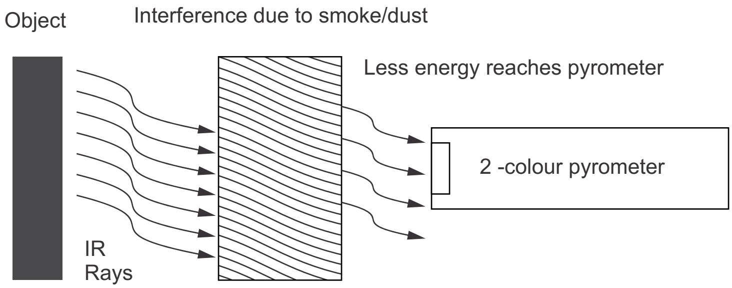
- Single color pyrometers
- Ratio type pyrometers (two colour pyrometers)
- Multi wavelength pyrometer

Single color pyrometers

These pyrometers operate over a narrow range of wavelengths. They are also called as single color pyrometers. They are normally used for measuring glass at 5.14 µm. Metals can also be measured as their rate of emissivity is high only in a narrow band. The spectral response of the particular device depends on the type of the detector used. For an instance, the response of a pyrometer with a silicon cell detector is around 0.9 - 1.1 microns. These pyrometers can work on selected wavelength range with the help of filters. But for this more sensitive detectors and advances in signal amplifiers are required.

Ratio radiation pyrometers (two colour pyrometers)

This pyrometer measures the radiated energy of an object between two narrow wavelength bands and then calculates the ratio of the two energies. This ratio is the function of the temperature of the object. This is also called as two colour pyrometer because the two wavelengths corresponded to different colors in the visible spectrum. Even if the object does not fully cover the spot the output signal will not change. Also the temperature measurement is independent of emissivity, so the errors caused by the emissivity variation, surface finish, and energy absorbing materials (e.g. smoke, smog, water vapor, etc.) between the pyrometer and the target can be minimized or removed (see Figure). It is used for measuring high temperature (e.g. molten metal).



Working of Pyrometer

Multi wavelength pyrometers

Accurate temperature determination cannot be made without knowledge of surface emissivity since emissivity can change with processing conditions, then clearly the only solution is to gain that knowledge while the temperature determination is being made.

An expert system multi wavelength pyrometer has been able to overcome many well known difficulties of pyrometry, including unknown, changing, and/or spectral dependence of emissivity as well as environmental absorption of radiation.

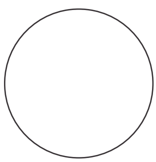
In addition to a multiple filter wheel for separation of wavelength and the usual optics, the instrument includes a software based on the data collected from numerous similar application which allows to analyze each measurement and then calculate the temperature, using the signal strength and surface properties.

Fiber optic radiation pyrometers

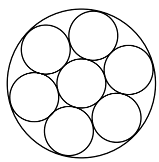
Optical pyrometers can be considered a subset of narrow band devices. Fiber optic pyrometers can be classified as wide band, narrow band, or ratio devices. These devices use an optical fiber (light guide) to direct the radiation to the detector (see Figure). The spectral response of these fibers is extended to about 2 microns so it is useful in measuring object temperatures to as low 100°C. An optical head, a glass fiber and a signal processing unit together forms a fiber optic pyrometer. The optical head doesn't contain any electronics. It is basically used where the sighting path to the target is not clear (pressure chamber). Some inherent advantages of fiber optics over other pyrometers are:

1. They are unaffected by strong electromagnetic fields therefore can be easily used where such type of interference fields are present.
2. It can be placed in hard-to-reach fields.
3. As it does not carry any electrical current, so it is ideal for explosive and hazardous locations.
4. Optical head and the fiber are free from any electronic components so cooling is not required and hence can be used to measure high temperatures (near about 250°C). However pyrometer unit requires cooling.
5. The diameter of a optical fiber is small therefore the small spot size can be obtained.

In an optical fiber the captured radiation is transmitted by total internal reflection. The inner layer is called core and outer layer is cladding. Therefore signal can be transmitted without any loss. Optical fiber consists either of a single fiber (mono-fiber) of multi-fiber.



Mono/Single Fiber



Multi Fiber

The comparison between a single fiber and multi-fiber is given below:

- Breakage in the mono fiber can be immediately detected than in multi fiber.
- No wear and tear is required for mono fiber but in multi fiber the cladding of individual fiber may get damaged due to friction amongst them.
- Multi fiber optical fiber is relatively less expensive and also their minimum curving radius makes them useful in many applications.

Fiber optic Pyrometer

7.9 Accessories

Pyrometer are available with a various accessories to solve a wide range of application condition. Here listed some of those mechanical and electrical/electronic accessories.

Mechanical Accessories:

1.Cooling Accessories : Facilitate the pyrometer to be operated at higher surrounding temperature and maintains internal temperature of electronics in the pyrometer.

- Radiation shield
- Cooling plate
- Cooling jacket

2. Mounting Devices : Used to fix pyrometer in a particular position.

- Angle brackets
- Adjustable Positioning devices

3. Flange Systems : Used to append the pyrometer to the furnaces, container or pipes.

- Mounting tube
- Lamination slide
- Ball and socket mounting

4. Sighting Accessories : It is very helpful to sight on the spot size for the measurement if moving objects and in poor light conditions.

- Sight tubes
- Laser pointing devices
- Scopes

5. Air Purge Units : It is attached to front end of sensor which protects the optics of the pyrometer from dust, smoke, moisture and other contaminations. It is in the form of round nozzle which and provides positive air pressure in front of the lens.

6. Emissivity Enhancer : It is used for shiny and highly reflective metal surfaces having very low emissivity at low temperatures. It is a goal plated concave mirror, which is mounted close to the measuring object. The incident radiation undergoes multiple internal reflection between the measuring object and the emissivity enhancer due to which the energy of infrared energy is mechanically increased. This mechanically increased energy is measured by the pyrometer through a small hole in the concave mirror which improve the result of temperature measurement.

7. Scanner : Scanner are used to move the spot size back and front across the target to be measured. It is used to measure the temperature of moving objects. Maximum value strong unit is always used with scanner. Scanner can be in built or attached to the front of the optics of pyrometer which assists them to be used as line scanners.

Electrical/Electronic Accessories:

1.Indicators and controller : This unit displays the measured signal as temperature (°F or °C). They are available from a simple digital panel meter to complex multi channel processors.

2. Digital Converter : Converts a RS 485 signal into a RS 232 signal.

3. Gateways : permits the conversion of RS 485 signals to several bus systems.

4. Calibrators : These are used to check the precision of the pyrometer.

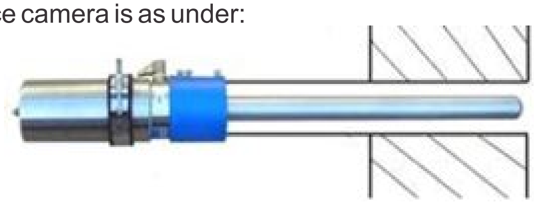
8
Furnace Monitoring System

8.1 Introduction

Furnace monitoring systems are essential for viewing inside conditions of the hot furnace. Traditionally peep holes were provided in the furnace for this purpose, but with advent of better protections and technology available for getting this picture ion the control room had provided a big advantage for the operator and the plant management.

Furnace monitoring cameras are being used for Cement, Steel, Glass and power plants; for viewing inside the rotating kilns, clinker coolers, melting furnace, boiler burner furnace etc.

The detail of advance furnace camera is as under:



Parts		Description
Vision Tube	Lens	Block-type : Easy assembly /disassembly by user. (Easy installation / maintenance & repair, cost saving)
	Camera	Ultra small high definition1/4" Sony CCD SENSOR camera installed inside the tube. (Decreased weight to enable self-powered retraction by windup - spring)
	Inner Tube	Part where block type lens is located.
	Outer Tube	Made of special material to protect inner tube from high temperature
Retractor	Windup Spring	Do not need to use motor or pneumatic of past. Using windup-springs. Vision tube can be retracted without a power source.
	Electric Lock	Prevents arbitrary retraction caused by spring elasticity. Receives signals from the control panel and unlock to enable automatic retraction.
Control Panel	Electric Control	Alarm goes off power when supply is cut. Sends signal to electric lock Automatic, manual, semi automatic control.
	Air Control	Alarm goes off when air-pressure goes below a certain level. Prevents damage to Vision Tube inflicted by high temperature inside furnace caused by a cut of air supply. Cooling Vision Tube by consistent provision of compressed air.

Special air cooled high temperature lenses with a color CCD cameras provide real time monitoring inside the boiler or furnace. The new furnace vision camera employs air cooled probe which is designed for continuous operation in furnace temperature up to 1700°C. The latest furnace monitoring system is built up in a block camera, which provides faster and cheaper maintenance of the furnace camera, which is a big problem faced with other camera on the market. The Ro-Ne-Vision system is much lighter and does not use water cooling. The retraction system assists in protecting the camera in case of failure of power of air supply for cooling the camera, reducing the chances of camera breakdown.

The system is flexible and easy to install on the furnace wall and incorporated a 68° horizontal and 50° vertical field of view; giving an overall better view. The traditional straight view lens tube is typically used for most wall fired boilers. The offset angle lens can be used in smaller tangential fired (corner-fired) boilers.

Thermal view camera is also available with a possibility of providing the average temperature display of any 32 points/area. The data can be used for control or can be recorded for further analysis.

8.2 Brief Application Details

8.2.1 Cement Kilns And Coolers

The kiln operator must have reliable data from the kiln to make best firing decision. The furnace camera provides the view of inside the kiln right in the control room. The furnace camera provides the view of the flame, monitoring the length, the direction and its effect on the feed. Better monitoring aids in getting the best operating conditions for the flame and helps with fuel efficiency. Flame temperature can be monitored as well when burning coal or petroleum coke, by observing color changes or choosing for the thermal imaging camera.

The camera for the coolers section provides the view inside the coolers and is important for monitoring the cement clinker condition, which is very important for the product quality.

8.2.2 Power Utility Boilers

Cameras have been used to view inside the coal and oil fired power utility boilers for decades to facilitate startup or "light off". The potential for explosion inside the boiler exists when the fuel does not light as it should, thus viewing this process helps prevent this type of unwanted reaction. In the past, flame detectors were used to assist in light-of but were not as reliable as necessary.

Black and white cameras were also used assistance but often pulled out once the boiler was on full load, since they rarely performed well across the full dynamic range of the boiler. Now, with the new systems it is possible to continuously monitor the furnace conditions.

The camera is positioned relatively low above the top row of burners while obtaining a full view of the entire boiler (all four corners). This is critical when the operator wants to see the entire "fireball". The fireball is formed by the combustion process of all the four corner burners. As the fuel is injected and ignites, a circular motion takes place and as heat rises, created a fireball reaction in the center of the boiler. Being able to see this fireball aids the operation in controlling overall burner performance and fuel costs.

8.2.3 Steel

The furnace camera provides a clear view of the steel slab progression in batch or continuous steel reheat furnace and the burner performance. The camera is ideally mounted near the exit of the furnace on the opposite sides above the products. The combined view of the cameras provides 360 degree view of the furnace.

The camera is also useful when mounted just below the height where the slab travels. This aids in viewing the level of scale deposited beneath the steel.

8.2.4 Glass

The furnace camera provides the clear view of the condition inside the glass furnace. This is used to check the molten glass condition, refractory healthiness and the firing pattern inside the furnace.

Thermal view is employed in some cases to provide the thermal view of the furnace. Recording of the data is possible to use for analysis of the refectory life etc.

These cameras are also used in the steel kiln applications for viewing the inside of the kiln and the burner flame.

The furnace camera mounted at the entrance of the rolling mill assists the operator in monitoring the slab as it enters the mill.

9
Inspection, Testing and Calibration

9.1 Inspection and Testing

For the assurance of the quality of Sensor different type of testing is done they are:

(I) Type Test & (ii) Routine Test.

- **(I) Type Tests :** The tests which are carried out to prove conformity with the requirements of the specification are called type test. These are intended to prove the general qualities and design of a given sample of sensor.
- **(ii) Routine Tests :** The tests which are carried out on each sensor as per sampling plan are called routine test.

The major tests for the assurance of the quality are as follows:

(a) Appearance and Structure Check : Visual inspection is made to confirm that the thermocouple assembly is in conformity with the specification, drawing and constituent materials. Visual checking are conducted on the finish of joints, junctions, welds, name/tag plates and other parts to confirm that there is no error, flaw dirt or irregularity on the surface finish. If necessary, dye penetration check, hydrostatic pressure test and X-ray inspection can be made on welded and joint parts.

(b) Dimensional Check : Unless otherwise specified, dimensional check is made in accordance with the following tables using Vernier Caliper, Straight Measure and Gauges.

Non MI Unit, mm		Non MI Unit, mm	
Nominal Length	**Tolerance**	**Nominal Length**	**Tolerance**
Below 1,000	±3.0	Below 250	±3.0
1,000 - 2,000	±5.0	250 - 1,000	±5.0
Over 2,000	±7.0	Over 1,000	±1.0%

(c) Insulation Resistance Test

Insulation Resistance Test is conducted using a Super megohmeter applying steep temperature gradient on sensor assembly immersed in a boiling water bath so as to accelerate condensation of moisture that might be entrapped in the assembly. This enables the measurement of insulation resistance of the assembly very precisely between terminal and sheath.

Sensor	Voltage	Insulation Resistance
Non MI	at room Temperature DC 500V	More Than 100MΩ
MI Dia - 2.0 and Below	at room Temperature DC 1000V	More Than 100MΩ
MI Dia - 3.0 and Above	at room Temperature DC 500V	More Than 100MΩ
RTD	at room Temperature DC 250V	More Than 100MΩ
T/C	at 560°C DC 500 V	More Than 5MΩ

(d) Emf Calibration Test

These tests can be made either by comparison method with standard thermocouples /RTD or absolute method using fixed point standards on every unit or batch at the pre-set three temperature points depending on the types of sensor.

(e) Pressure Test (For Sealed Elements Only)

The element shall be tested in a hydraulic test chamber containing water and ice in equilibrium and connected electrically to an appropriate indicator. The pressure of the fluid in the chamber shall be raised to 35kgf/cm and shall be maintained for 15 minutes.

The resistance or EMF of the element shall not vary significantly from that appropriate to the equilibrium temperature corresponding to the pressure applied and when subsequently removed from the chamber, the element shall pass insulation resistance test and accuracy test.

(f) Identification Test on the Thermocouple Type and Polarity

Either by dipping thermocouple assembly into the above boiling water bath or applying hot air-blow/flame heat on the beaded Thermocouple at its hot or cold end to have it generate EMF, which allows to indicate specific type of thermocouple through Temperature vs. EMF Table. A high resolution D.C. circuit testing instrument is used to identify the type of thermocouple and polarity of the thermocouple leg and terminal.

(g) Others

Loop Resistance test, voltage withstand test, X-ray test, vibration test, pressure test, helium leak test, etc. can also conducted upon request.

9.2 Calibration

Temperature is one of the most frequently measured parameters in industrial processes. Wide varieties of mechanical and electrical thermometers are used to sense and control process temperatures. Regular calibration of these thermometers is critical to ensuring consistent quality of product manufactured, as well as providing regulatory compliance for some industries.

Calibration is a comparison between measurements - one of known magnitude or correctness made or set with one device and another measurement made in as similar a way as possible with a second device.

The device with the known or assigned correctness is called the standard. The second device is the unit under test, test instrument, or any of several other names for the device being calibrated.

Calibration is performed to verify sensor/instrument performance. Calibration is the process used to ensure that a sensor/instrument maintains specification over time and changing ambient conditions. Calibration is the process used to maintain traceability of parameters with reference to national/international standards.

There are many definitions of calibrations as there are methods: According to ISA's The Automation, Instruments and Systems dictionary, The word calibration is defined as "A test during which a known value of measurand are applied to transducers and corresponding output readings are recorded under specified conditions ". The definition includes the capability to adjust the instrument at zero and to set the desired span. An interpretation of definition would say that the calibration is a comparison of measuring instrument against a standard instrument of higher accuracy to detect, correlate, adjust, rectify and document the accuracy of the instrument being compared.

9.2.1 Types of Thermal Calibration

There are mainly two types of calibrations method used they are, Fixed point method and comparison method.

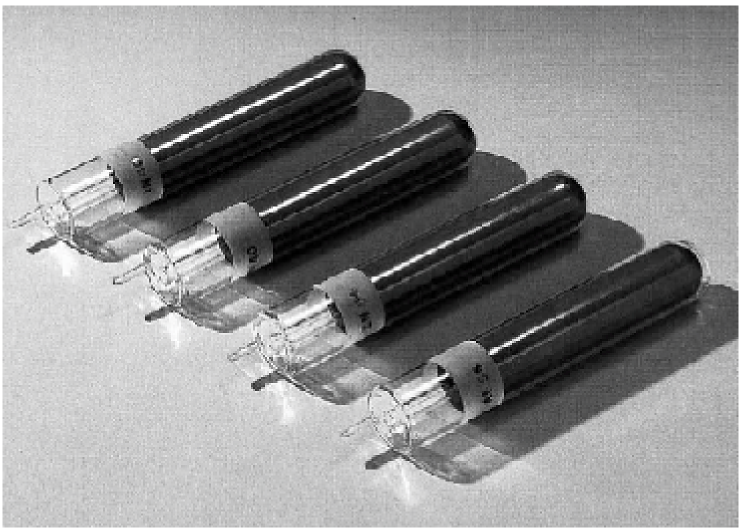
a.) Fixed Points

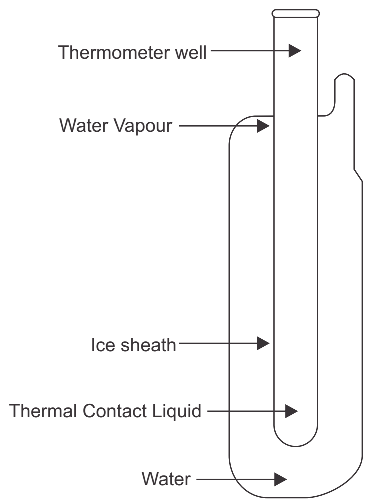
Fixed points are the most accurate devices available for defining a temperature scale. Fixed point devices utilize totally pure materials enclosed in a sealed, inert environment; they are usually fragile and need to be handled with care.

The housing incorporate isothermal blocks with wells into which the probes are placed. Since fixed point temperatures are defined by physical laws, comparison of the test probe to a reference probe is not required.

Fixed point calibrations are used for primary temperature standards to achieve the lowest possible uncertainties. It is a time consuming method and requires the use of expensive fixed point cells.

The triple point of water (TPW) cell may be the most commonly used type of fixed point and is used in ITS 90 calibrations. Water can exist as a solid, liquid, and vapor at 0.01°C and this device creates this temperature.





Triple point of water cell

Fixed points method

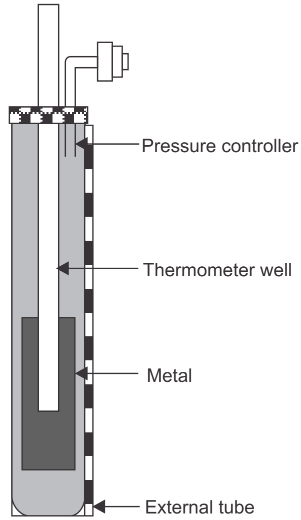
This absolute method is used for the realization of the International temperature scale, ITS-90. The thermometer is calibrated by measurements at a series of temperature fixed points: e.g. freezing/melting points, triple points, vapour pressure points.

This method consists in setting up a thermometer in a fixed-point cell that provides an isothermal environment.

The fixed point cell is a flask almost completely filled with pure material and protected by a shell. The cell is placed in an apparatus that must provide good temperature control and sufficient cell immersion to generate a uniform temperature in the measurement zone. The apparatus must provide for fixed-point cooling as well as controlled heat. It may be a furnace - generally, a vertical tube furnace with suitable insulation - or a liquid bath.

A number of fixed points are chosen. They should be as few as possible, consistent with the need to establish a good interpolating formula. This method gives a highly accurate calibration and is used only for highest quality thermometry. But it is difficult to undertake because of the complexity of the equipment and the many precautions that must be taken to realize the fixed points successfully.

Fixed points are realized using numerous pure substances. However, many do not ensure the required stability and reproducibility and others require a complex procedure and special laboratory facilities.



ITS 90 fixed points include:

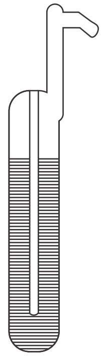
Boiling point of Nitrogen	-195.798°C
Mercury triple point	38.8344°C
Triple point of water	0.01°C
Melting point of Gallium	29.7646°C
Freezing point of Indium	156.5985°C
Freezing point of Tin	231.928°C
Freezing point of Lead	327.462°C
Freezing point of Zinc	419.527°C
Freezing point of Antimony	630.63°C
Freezing point of Aluminum	660.323°C
Freezing point of Silver	961.78°C

Triple Point Of Water 273.16.K (0.01°C)

The triple-point temperature of water is assigned the value 273.16 K on the Kelvin Thermodynamic Temperature Scale and also on the ITS-90. It is the reference temperature for resistance ratios in platinum resistance thermometry. The water used in preparing triple point of water cells is pure water of naturally-occurring isotopic composition. Figure 6 shows two commonly used types of triple point of water cells.

Triple point of water cells are usually prepared from river water that has been purified by chemical treatment and distillation. River water is expected to have concentrations of deuterium and the heavier

isotopes of oxygen that are lower than that of ocean water. The extreme difference in the triple points of naturally occurring water, including polar water, is given as 0.25 mK. It is expected that differences among water triple-point cells of river water would be much smaller than 0.25 mK. (The isotopic composition difference between river water and ocean water has been estimated to cause no more than a 0.050 mK difference in the triple-point temperature.) While the basic material is plentifully available, preparation of water triple-point cells requires a special effort. Although the effect on the triple-point temperature is negligible, a trace of air always remains in most sealed triple point of water cells. When a cell at room temperature is gently inverted from one end to the other and a sharp "click" is produced through the water hammer action, the amount of gas in the cell wi11 have negligible influence on the triple-point temperature

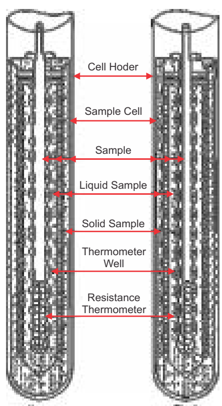


Two types of triple point of water cells with wells for platinum resistance thermometers. The cells contain pure air-free water. The thermometer wells are made of precision-bore tubing.

Freezing, Melting, Or Triple Points Of Metals: Hg Ga. In. Sn. Zn. Al. Ag Au. or Cu

The realization of metal fixed points requires the continuous presence of liquid-solid or liquid-solid-vapor phases in thermal equilibrium. With SPRT's, the liquid-solid interface, i.e., the equilibrium whose temperature is measured must surround and must be as close to the temperature sensing element as possible. Since the first cryoscopic constants of metals are relatively low, the fixed-point metal samples should be at least 99.9999% pure. Figure 1 shows idealized liquid/solid equilibrium conditions inside fixed point cells used in freezing and melting experiments.

Figure 2 shows a representative arrangement of an SPRT inserted inside a metal fixed point cell. Ideally, and similar to the water triple-point cell, an outer liquid-solid interface, which completely surrounds the inner interface, exists close to the container wall. This outer interface, which has a temperature very close to that of the inner interface, thermally protects and thermally stabilizes the inner interface.



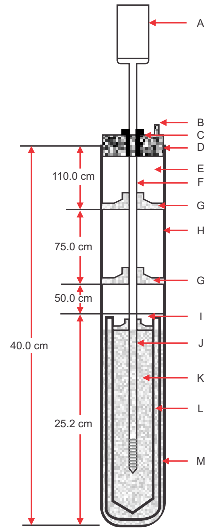
Idealized liquid/solid equilibrium conditions inside fixed point cells used in freezing and melting experiments

Figure An SPRT in a metal freezing-point cell.

In freezing experiments, a layer of solid is first formed at the crucible wall, and then a thin layer of solid is induced on the thermometer well by inserting cooling rods. As freezing advances, the outer interface approaches the inner interface until all of the material is solid. In melting experiments, a layer of liquid is first formed next to the crucible, and then a thin layer of liquid is formed next to the thermometer well by inserting a warming rod or a long heater. As melting advances, the outer liquid/solid interface approaches the inner interface.

Since different furnace or bath designs are required for fixed-point cells operated at different temperatures, they will1 be discussed along with each of the fixed points, or references will be made to appropriate sources of descriptions.

In radiation thermometry, the liquid-solid phase of the metal fixed point must completely surround the blackbody radiator capacity.



An SPRT in a metal freezing-point cell.

b.) Comparison method

In the comparison method we need :

a.) Stable temperature source

b.) Calibrated master sensor

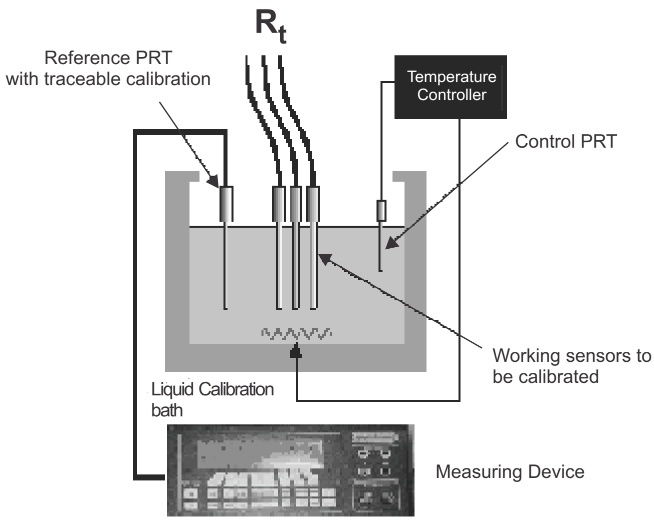
c.) Calibrated meter

The calibration environment to choose depends on the temperature range, as follows:

- For low temperature calibration (typically below -180°C) a vacuum-jacketed copper block.
- Above -90°C and up to 300°C a controlled stirred liquid bath is the most common means of calibration. Freon or alcohol may be used from -90°C, water at room temperature, oil to 300°C.
- For temperatures up to 600°C a salt bath/fluidized bath/dry block may be used.
- For higher temperatures furnaces are more appropriate. Many designs exist. Some have low thermal mass and rapid response; others have large thermal mass and slow response.

To minimize or reduce temperature gradients within a bath or furnace, a metal equalizing block is inserted, with thermo wells to receive both the standard and the thermometer(s) to be calibrated. This method allows a wide range of temperatures to be covered, point by point or continuously, in a short time, and to calibrate simultaneously a great number of thermometers. Nevertheless, the comparison method is less accurate than the fixed point method because of the lesser accuracy and stability of the reference standard and enclosure.

Comparison calibrations can be performed in a laboratory or in the field. High accuracy can be obtained with careful selection of equipment. Durability is an important as accuracy when used for field calibrations. Equipment that cannot stand up to field use will drift quickly and not provide the expected measurement uncertainties.



Cold junction Compensation (CJC)

To make accurate measurements for thermocouples, this must be compensated for by using a technique known as cold junction compensation (CJC). As the law of intermediate metals states that a third metal, inserted between the two dissimilar metals of a thermocouple junction will have no effect provided that the two junctions are at the same temperature. This law is also important in the construction of thermocouple junctions. It is acceptable to make a thermocouple junction by soldering the two metals together as the solder will not affect the reading. In practice, thermocouple junctions are made by welding the two metals together (usually by capacitive discharge). This ensures that the performance is not limited by the melting point of solder.

All standard thermocouple tables allow for this second thermocouple junction by assuming that it is kept at exactly zero degrees centigrade. Traditionally this was done with a carefully constructed ice bath (hence the term 'cold' junction compensation). Maintaining an ice bath (at 0ºC) is not practical for most measurement applications, so instead the actual temperature at the point of connection of the thermocouple wires to the measuring instrument is recorded.

Typically cold junction temperature is sensed by a precision thermometer in good thermal contact with the input connectors of the measuring instrument. This second temperature reading, along with the reading from the thermocouple itself is used by the measuring instrument to calculate the true temperature at the thermocouple tip. Understanding of cold junction compensation is important; any error in the measurement of cold junction temperature will lead to the same error in the measured temperature from the thermocouple tip.

c.) Electrical Calibration - Simulators and Sources

Indicators and controllers are calibrated by injection signals which simulate thermocouples, resistance thermometers or thermistors. A simulator provides a very quick and convenient method for calibrating an instrument at many points.

Very sophisticated and highly accurate laboratory instruments are available to permit on-site checking and calibration with a good level of accuracy.

9.2.2. Equipment required for a Calibration System

The equipment required to achieve thermal calibration of temperature probes is dependent on the desired accuracy and also ease of use. The greater the required accuracy, the more demanding the procedure becomes and of course, the greater the cost.

The required equipment generally falls into one of three groups

1. General purpose system for testing industrial plant temperature sensors will usually provide accuracies between 1.0°C and 0.1°C using comparison techniques.
2. A secondary standards system for high quality comparison and fixed point measurements will provide accuracies generally between 0.1°C and 0.01°C.
3. A primary standards system uses the most advanced and precise equipment to provide accuracies greater than 0.001°C.

Typical equipment used for comparison calibration is a standard or secondary PRT, several temperature baths, and a data acquisition system.

a.) Temperature Sensor

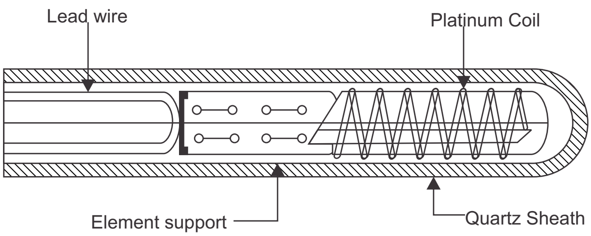
For lower temperature calibration Platinum resistance detector is used in the form of SPRT and RTD, these are very stable and accurate. For higher temperature calibration, Noble metal thermocouple is used like R, S type thermocouple. These sensors must have accuracy and repeatability. The detail of these temperature sensors is described in previous chapters and SPRT & SSPRT is discussed below:

Standard PRT's

A standard platinum resistance thermometer (SPRT) is the most accurate standard available, however, it is the most expensive standard, and other standards are acceptable alternatives depending upon the temperature range covered, the accuracy desired, the capabilities, or the preference of the calibration laboratory.

SPRT is a specially constructed assembly using a close tolerance Pt100 sensing resistor or a specially wound platinum element with a choice of Ro values. Construction is such as to eliminate the possibility of element contamination and various techniques are utilized to end this, such as special sheath materials, gas filling and special coil suspension.

Standard PRT's is Very fragile. This is mainly use in laboratory environments. Highest accuracy, high repeatability, low drift -200°C to 661°C, accurate to ±.001°C.



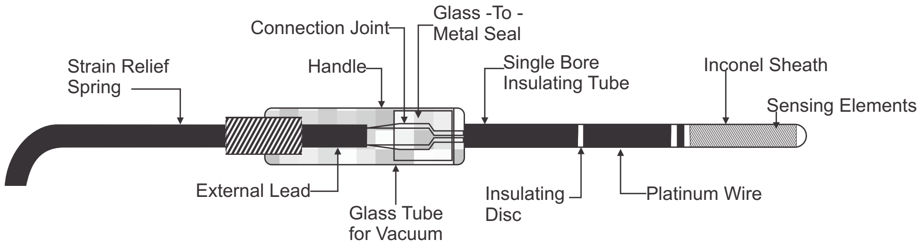
Secondary SPRT

The secondary standard PRT's is much more user friendly and can survive mild handling mishaps. It is less expensive than an SPRT. Metal Sheathed Semi Standard Platinum Resistance Thermometer are widely used as references to calibrate various temperature probes, particularly in secondary calibration laboratories.

The structure of the thermometer is similar to that of SPRTs. The differences include the applications of certain techniques to protect the element from contamination at high temperatures and mechanical shocks.

Basic Construction of SSPRT

SSPRT is constructed with a 6 mm outer diameter Inconel Sheath for high durability. Inside the sheath, the sensing element is protected by a thin platinum housing that shields the sensor from contamination from free floating metal ions found within metal environment at high temperatures. A special powder mixture is filled into the sensor capsule to support the element wire to protect the element from mechanical shocks. After all element parts and powder are assembled into the sensor protection capsule, a pure mixture of gases, including oxygen, is filled into the sensor at high temperature. The sensor is hermetically sealed under pressure. The unit is hermetically sealed using a glass to metal seal.



Improving Stabilities of SSPRT

There is a trade-off between the oxidation effect and element contamination in metal sheathed semi standard platinum resistance thermometer. Excessively high O2 leads to sensor contamination. The oxygen content in a thermometer may become unknown after a period of operation due to slow oxidation of the metal sheath and consequent loss of oxygen in metal sheathed SSPRT.

A feasible solution to protect against contamination is to seal the element separately from its sheath. This solution can resolve the conflict between the oxidation effect and element contamination and improve the long term stability of Metal Sheathed SSPRTs.

Master thermocouple

Industrial thermometers come in a variety of forms and types, calibrating them can be quite complicated.

To calibrate industrial sensors the laboratory must compare them to standard thermometers whose characteristics have been defined and are traceable to National Standards. Such thermometers that are traceable to national standard are known as 'Master thermocouple'.

Master thermocouple is use as a reference sensor in comparison type calibration process.

Master thermocouple is put in the highly stable temperature zone along with sensor under calibration, their reading is compared and error is calculated.

Master thermocouple should have high accuracy, and repeatability and should be recalibrated after certain period of time (generally time period suggested by calibration Laboratories).

b.) Temperature readout method

These instruments measures the output of the sensors, they must have high resolution and good accuracy.

c.) Secondary Temperature source

Dry block calibrators

Dry block calibrators provide the most convenient, portable facilities for checking industrial probes and they usually achieve reasonably rapid heating and cooling. The units consist of a specially designed heated block within which is located an insert having wells for the probes. The block temperature is controlled electronically to the desired temperature. The whole assembly is housed in a freestanding case. Although the block temperature is accurately controlled, any indication provided should be used for guidance only. As with any comparison technique, a certified sensor and indicator should be used to measure the block temperature and used as a reference for the test probe.

Black Body furnace is also a dry bath, but used in non contact calibration. The black body furnace has been designed to provide stable and accurate temperature to provide stable and accurate temperature to enable professionals to calibrate non contact radiation pyrometer by comparison method.

Stirred liquid baths

Stirred liquid baths provide superior thermal environments for probe immersion since no air gaps exist between the probe and medium. Thermal coupling is therefore much better than the alternatives described, and stirring results in very even heat distribution throughout the liquid.

With the help of this bath, the comparison calibration accuracy can be considerably greater than that which can be achieved in any metal block bath. It also has a larger calibration area, that allows more probes to be calibrated and a greater immersion depth which provide a superior thermal environment for probe immersion since air gaps exists between the probe and the medium. Thermal coupling is therefore much better than the alternatives described and as a result of stirring heat distribution is very even throughout the liquid.

Water from 0ºC to +80ºC and oils for up to 300ºC, Various molten salts and sand baths are used for temperatures in excess of 300ºC.

Ice bath and negative bath

Ice Bath

The ice bath is made up of a mixture of melting shaved ice and water. The ice bath is a convenient and inexpensive way to achieve an ice point; it can be reproduced with ease and with exceptional accuracy.

Junctions formed between the thermocouple materials and instrument leads can be simply immersed into the slush mixture, or alternatively glass "U" tubes containing a quantity of mercury approximately 3/4" to 1" depth can be placed into the slush mixture. Quick electrical connection can then be made between thermocouple and instrument leads through the mercury.

Negative temperature bath and Ice bath is mainly used for RTD calibration which provides negative temperature for low temperature calibration application. In this device a compressor and CFC gas is used for cooling purpose. Methanol is used as a medium for temperature below 0ºC.

Fluidized calibration baths

The fluidized calibration bath is a unique method of providing closely controlled temperatures. The bath consists of a very fine mesh aluminum oxide, a heated chamber into which the medium is placed, and a means for slowly agitating the bath by introducing a flow of air. By careful control of heat input and air flow, temperatures of the bath can be controlled within close limits thereby producing isothermal conditions between the calibration standard and the test setup. Fluidized beds are useful for calibrating over the temperature range from ambient to 700°C.

9.3 Uncertainty Factor

In earlier days, in general, the error or inaccuracy of a test instrument was a matter of concern when using the test instruments as reference. The concept of uncertainty is very frequently used in the calibration of precision equipments, where high degree of accuracy is required for measurement. This concept is considered for various important parameters.

Nowadays, calibration Labs are required to calculate and affix a total or expanded uncertainty for all measurements during calibration of a test instrument. It must be noted that 'error' is not 'uncertainty'.

TYPICAL CALIBRATION REPORT

TEMPSENS

C-0321

TEMPSENS CALIBRATION CENTRE
A Division of Tempsens instruments (I) Pvt. Ltd.
B-188A, ROAD NO.5, M.I.A., UDAIPUR-313003 INDIA
Ph.: +91-294-3057724,3057700 Fax : +91-294-2492447, 3057750
Email : info@tempsens.com, Website : www.tempsens.com

Calibration Certificate
No. TL/211/201.2.1

M/S XYZ Address 1 Address 2 City State	J.O. No.: X000/Y/ABCD J.O. Datet. : DD- MM-YY Received Dt. : DD- MM-YY Calibration Dt. : DD- MM-YY

UUC Description :
One sample describes as PTRH13%-PT "R" TYPE THERMOCOUPLE Sr. No. TTCR-13 ; was received.

Calibration Required at °C : 250, 500, 750, 1000, 1200, 1500

Calibration Procedure : The UUC was allowed to equiilibrate within controlled stable thermal environment, along with a standard sensor. The reading of sensor were recorded at specified temperature point. As per work instruction no. WI-LAB-17. The report provide the reading and deviation at the specified Point
Temperature (in °C) against thermocouple reading (in µV) are calculated by using ASTM E-230 /IS table.

The Thermocouple has been compared with the following working standard of sensor & measuring instrument.

Standards	Traceable To	Certificate No.	Valid Upto
MASTER "RTD" - Pt100	INT. STD. (DKD)	3013	30-05-12
THERMOCOUPLE "S" TYPE		13153	28-01-12
THERMOCOUPLE "B" TYPE	NAT. STD. (NPL)	10011555/1.03B/C-91/09	01-02-12
CALSYS 300			
CALSYS 1200L			
CALSYS 1500L			
PRECISION THERMOMETER	NST. STANDARTD	YMPL/174251/27718	18-01-12

The result of calibration are as under :
(Reference junction calculated at 0°C)

Sr.	Standard Sensor	UUC		Deviation	Expanded Uncertainty
	Temp °C	mV	Temp °C	Temp °C	± °C
1	249.77	1.92	250.06	0.29	0.10
2	499.84	4.47	500.31	0.47	1.07
3	750.03	7.35	750.78	0.75	1.30
4	1,000.38	10.52	1,001.41	1.03	1.30
5	1,200.29	13.25	1,201.46	1.17	2.20
6	1,498.09	17.44	1,499.53	1.44	3.70

Temperature Scale : ITS - 90 Ambient Temp. : 25±2°C Relative Humidity : 50±20%

Calibrated By **Checked By** **Certified By**

Note : (1) The calibration result reported in this certificate are valid at the time of and under the stated condition of measurement for the particular sampl
(2) The report shall not be reproduced except in fill, without written permission of the laboratory
(3) Coverage factor "K" = 2 at 95.45% confidence level.

TEMPERATURE SENSOR TECHNOLOGY

TYPICAL CALIBRATION REPORT FOR FIXED POINT CALIBRATION

TEMPSENS

C-0321

TEMPSENS CALIBRATION CENTRE
A Division of Tempsens instruments (I) Pvt. Ltd.
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Ph.: +91-294-3057724,3057700 Fax : +91-294-2492447, 3057750
Email : info@tempsens.com, Website : www.tempsens.com

Calibration Certificate

No. AB/000/000.0.0

TEMPSENS CALIBRATION CENTRE **A DIV OF TEMPSENS INSTRUMENTS (I) PVT. LTD.** **B-188A, ROAD NO. 5, M.I.A., UDAIPUR** **(RAJ) - 313003**		**CALIBRATION CERTIFICATE OF** STANDARD PLATINUM RESISTANCE THERMOMETER **Certificate No.** **AB/000/000.0.0**	
Date	**Recommended date for the next calibration**	**Page**	**No. Of pages**
DD/MM/YYYY	**DD/MM/YYYY**	**1**	**28**

1. Calibration for : **XYZ Limited**
Address 1
Address 2

2. Discription & Identification of instruments : Semi standard platinum resistance thermometer
Make : Tempsens Sr. No. : 1428
Range : 0°C to 660°C

3. Environmental Conditions : Temprature :(25±2)°C
Humidity : (50±20)% RH

4. Standard(s) Used & Associated uncertainty : Fixed Point of T.P. of water, melting point of Ga, Freezing point of Sn, Zn, & Al.
:SPRT (25.5)
: Expanded Uncertainity at K = 2 & C.L. = Approx. 95% (±15 m°C to 40 m°C)

5. Traceable of Standard : The standard used for calibration are traceable to National Standards.

6. Principle / Methodology of Calibration : The PRT110 has been calibrated by fixed point method at T.Ps of water, M.Ps of Ga F.Ps of Tin, Zinc & Aluminium. The fixed point are being maintained at Tempsens calibration centre, Udaipur as per ITS-90 (Calibration Procedures # P-LAB-10)

7. Result : **For the range 0.01°C to 660.323°C**

W (Ga) = 1.1157072664
W (Sn) = 1.87467542843
W (Zn) = 2.53724084208
W (Al) = 3.32791714936

A = -2.10866869208829 E-02
B = 5.63003096097834 E-04
C = -1.62849222411736 E-04

R(TPW) = 100.132Ω

R (Ga) = 111.718
R (Sn) = 187.715
R (Zn) = 254.059
R (Al) = 333.231

The Estimated uncertainties for k = 2 & C.L. = approx. 95% are as follows :
T.P. OF Water = 0.015°C, M.P. OF Ga = 0.029 F.P. of Sn = 0.039°C,
F.P. of Zn = 0.035°C, F.P. ofAl = 0.040°C

Calibrated By **Checked By** **Certified By**

TEMPERATURE SENSOR TECHNOLOGY

10
Electronics & Instrumentation for Temperature

10.1 Introduction

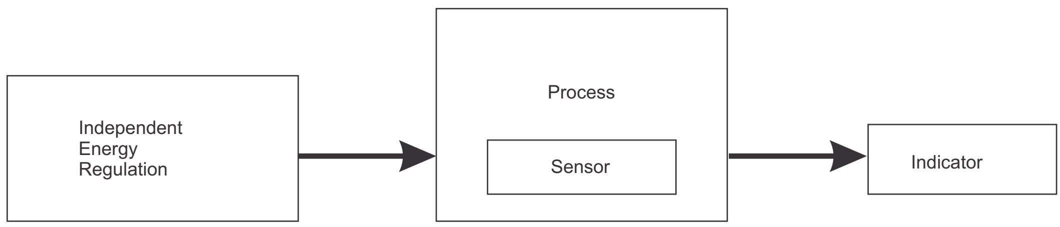
The range requirement in instrumentation ranges from a simple display of a single temperature value to multi sensor data acquisition and logging or from a simple controller to multi zone communicating control systems. Other requirements may include transmission and signal conditioning, analogue recording, alarm monitoring and communications.

Fundamentally, instrumentation will be in one of the two forms, open loop or closed loop. Open loop is where there is no system feedback and therefore no control action; the measuring instrument(s) exerts no influence over the process behavior other than possible alarm action, which may result in "power-down".

Closed loop is where there is direct or indirect feedback from the instrument to the process energy temperature regulator resulting in control of the process temperature.

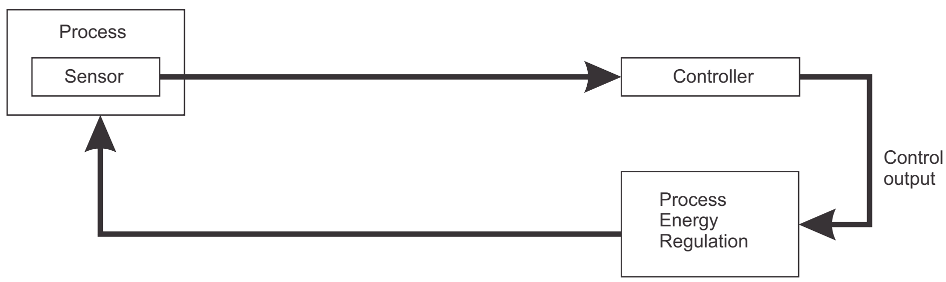
10.2 Temperature Indicators

Temperature indicators are the basic instruments which are required either locally or required in the control room for the process parameters monitoring.



Sensor simply provides temperature information to the indicator.
Process regulation is effected independently

Open Loop System



Sensor provides temperature feedback thus allowing automatic control

Closed Loop System

10.3 Temperature Indicators

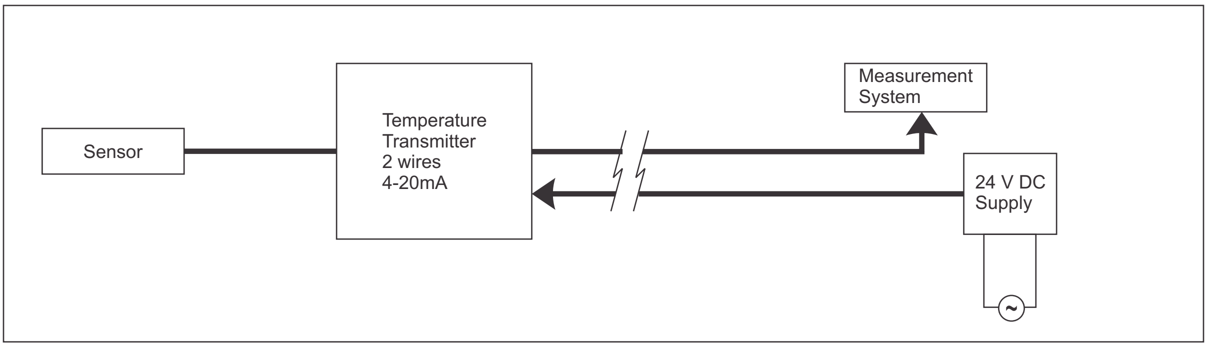
Temperature indicators are the basic instruments which are required either locally or equired in the control room for the process parameters monitoring.

Display Size	0.8", 1", 3", 4" and 8"
Digits	31/2, 4 digit
Size	48x96 mm, 96x96 mm or large
Supply	230VAC or 24VDC
Input	Thermocouple K, J, T, R, S, B, RTD, mA, V

10.4 Transmitters And Signal Conditioning

Temperature transmitters are widely used in measurement systems because their use allows long cable run back to the associated instrumentation. They also perform signal conditioning.

A 2-wire temperature transmitter accepts a thermocouple or 3 wires PT100 input and convert the "temperature" output into a 4-20 mA current signal. The transmitter usually requires a 24v dc supply, which is connected in series with the 2-wire interface (or is provided by the host instruments). The amplified temperature signal can be transmitted via a long cable run if required, a considerable advantage with large site installation.



Temperature Transmitter Circuit

The output can either be linear with temperature (usually the case with Pt100 inputs) or linear with thermocouple voltage (not linear with temperature usually the case with thermocouple inputs). It is important to as certain linearity or otherwise since this will have ramification as far as the indicator is concerned. If the interface is non-linear with temperature, the indicator must display the appropriate transfer characteristic in order to give an accurate temperature readout (e.g. scaled for the Type K curve).

Transmitter scaling must be specified as required e.g. 0°C to 400°C = 4 to 20mA.

Remember, this must correspond to the instrument scaling to avoid measurement errors. Input to output isolation is not necessarily incorporated as standard and it is essential to use electrically insulated sensors if isolation is not incorporated.

Signal conditioning is the process of modifying the raw input signal in one or more ways to facilities communication and measurement. The transmitter is a simple form of signal conditioner but signal conditioners usually provide linearization, scaling facilities and other functions. The most common form of signal conditioner housing is a DIN rail-mounting module.

Signal conditioners are particularly useful when different parameters are in a process (e.g. Pt100 and thermocouple outputs, flow rates, pressure and force). The output from all of the appropriate sensors or transducers can be rationalized into a common interface such as 4-20mA or 1-5V. Transfer characteristics can also usually be applied to suit a range of sensors and transducers resulting in a linear function.

On this basis, standard process indicators can be utilized thus simplifying instrumentation.

Programmable and so-called "smart" transmitters effectively combine transmission and signal conditioning function. In addition to manipulating the input-output function, a variety of transmission modes can be selected. Isolation of input to output further enhances their scope of application; for example a multi- sensor installation with individual transmitters can be used without danger of earth loops establishing spurious potentials. Programming is performed via a PC using software normally supplied or via plug- in mode.

10.5 PID Explained

Only very crude control of temperature can be achieved by causing heater power to be simply switch on and off accordingly to an under or over temperature condition respectively. Ultimately, the heater power will be regulated to achieve a desired system temperature but refinement can be employed to enhance the control accuracy.

Such refinement is available in the form of proportional (P), integral (I), and derivative (D) function applied to the control loop. These function, referred to as control "terms" can be used in combination according to system requirement.

The desired temperature is usually referred to as the set-point (SP).

To achieve optimum temperature control whether using on off, P, PD, or PID techniques, ensure that:

Adequate heater power is available (ideally control will be achieved with 50% power applied).

The temperature sensor, be it thermocouple or PRT, is located within reasonable "thermal" distance of the heater such that it will respond to change in heater temperature but will be representative of the load temperature (the "thing" being heated).

Adequate "thermal mass" in the system to minimize its sensitivity to varying load or ambient condition.

Good thermal transfer between heater and load.

The controller temperature range and sensor type are suitable try to choose a range that result in a mid-scale set point.

10.5.1 Control Function Simply Described

10.5.1 (a) ON OFF : usually simplest and cheapest but control may be oscillatory. Best confined to alarm function only or when "thermostatic" type control is all that is required, but this may be the most suitable means of control in some application.

10.5.1 (b) Proportional (P) : a form of anticipatory action, which slows the temperature rise when approaching set point. Variation is more smoothly corrected but an offset will occur (between set and achieved temperature) as condition varies. Average heater power over a period of time is regulated and applied power is proportional to the error between sensor temperature and set point. The region over which power is thus varied is called the proportional band it is usually defined as a percentage of full scale. Offset is the deviation of the sensor temperature from the desired value. This can be adjusted out manually by means of a potentiometer adjustment or automatically.

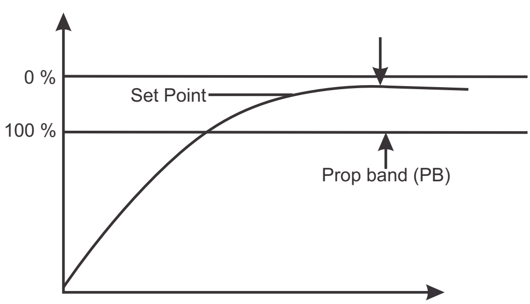
10.5.1 (c) Proportional + Derivative (PD) : the derivative term when combined with proportional action improve control by sensing change and correcting for them quickly. The proportional action is effective intensified to achieve a quicker response.

10.5.1 (d) Proportional + Integral + Derivative (PID) : adding an integral term to Pd control can provide automatic and continuous elimination of any offset. Integral action operates in the steady state condition by shifting the proportional band upscale or downscale until the system temperature and set point coincide.

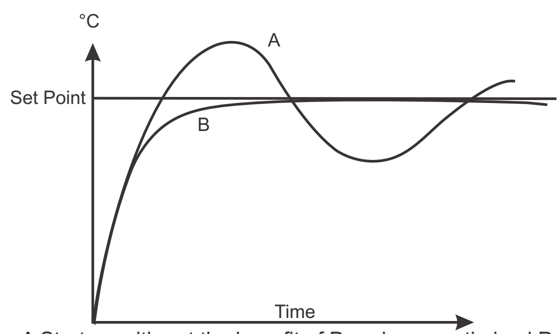
10.6 Choosing P, PD or PID :
although superior control can be achieved in many case with PID control action value of the PID terms inappropriate to the application can cause problem.

If an adequately powered system with good thermal response exists and the best possible control accuracy is required, full PID control is recommend.

If somewhat less critical precision is demanded, the simpler PD action will suffice and will suit a broad range of application.



Proportional Control



A Start up with out the benefit of D and non- optimized P.
B Start up with optimized PD and overshoot inhibition

11.7 Proportional Plus Integral Plus Derivative Control Mode (PID)

This controller operates the same way a proportional controller does, except that the function of the trim adjustment is performed automatically by the integral function (automatic reset). Thus, load changes are compensated for automatically and the temperature agrees with the setpoint under all operating conditions. Offset is eliminated.

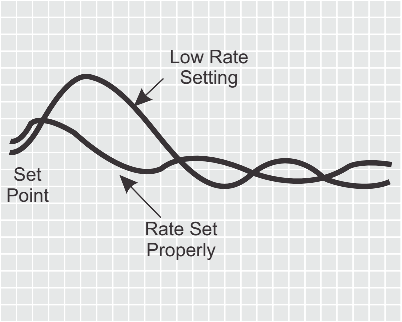


Figure : Rate function compensates for rapid changes.

The derivative function (rate action) compensates for load changes which take place rapidly. An example is a traveling belt oven where the product is fed intermittently. When the product enters the oven, there is a sharp rise in the demand for heat, and when it stops, there is an excess of heat. Derivative action reduces the undershoot and overshoot of temperature under these conditions and prevents bad product due to over or under curing. PID control provides more accurate and stable control than on/off or proportional controller types. It is best used in systems that have a relatively small mass and which react quickly to changes in energy added to the process. It is recommended in systems where the load changes often. The controller is expected to automatically compensate the amount of energy available or the mass to be controlled, due to frequent changes in setpoint. The proportional, integral and derivative terms must be "tuned," i.e., adjusted to a particular process. This is done by trial and error. Some controllers called Autotune controllers attempt to adjust the PID parameters automatically.

11.8 PID Controller Operation

The PID controller provides proportional with integral and derivative control. This controller combines proportional control with two additional adjustments, which helps the unit automatically compensate for changes in the system. These adjustments, integral and derivative, are expressed in time-based units; they are also referred to by their reciprocals, RESET and RATE, respectively.

The proportional, integral and derivative terms must be individually adjusted or "tuned" to a particular system using trial and error. It provides the most accurate and stable control of the three controller types, and is best used in systems which have a relatively small mass, those which react quickly to changes in the energy added to the process. It is recommended in systems where the load changes often and the controller is expected to compensate automatically due to frequent changes in setpoint, the amount of energy available, or the mass to be controlled.

There are also other features to consider when selecting a controller. These include auto- or self-tuning, where the instrument will automatically calculate the proper proportional band, rate and reset values for precise control; serial communications, where the unit can "talk" to a host computer for data storage, analysis, and tuning; alarms, that can be latching (manual reset) or non-latching (automatic reset), set to trigger on high or low process temperatures or if a deviation from setpoint is observed; timers/event indicators which can mark elapsed time or the end/beginning of an event. In addition, relay or triac output units can be used with external switches, such as SSR solid state relays or magnetic contactors, in order to switch large loads up to 75 A.

11.9 Solid State Relays(SSR)

SSR Defined. A solid-state relay is an ON-OFF control device in which the load current is conducted by one or more semiconductors - e.g., a power transistor, an SCR, or a TRIAC. (The SCR and TRIAC are often called “thyristors,” a term derived by combining thyratron and transistor, since thyristors are triggered semiconductor

switches.) Like all relays, the SSR requires relatively low control circuit energy to switch the output state from OFF to ON, or vice versa. Since this control energy is very much lower than the output power controllable by the relay at full load, "power gain" in an SSR is substantial--frequently much higher than in an electromagnetic relay of comparable output rating. To put it another way, the sensitivity of an SSR is often significantly higher than that of an EMR of comparable output rating.

Types of SSR's : It is convenient to classify SSR's by the nature of the input circuit, with particular reference to them means by which input-output isolation is achieved. Three major categories are recognized:

- Reed-Relay-Coupled SSR's ,in which the control signal is applied (directly, or through a preamplifier) to the coil of a reed relay. The closure of the reed switch then activates appropriate circuitry that triggers the thyristor switch. Clearly, the input-output isolation achieved is that of the reed relay, which is usually excellent.
- Transformer-Coupled SSR's, in which the control signal is applied (through a DC-AC converter, if it is DC, or directly, if It is AC) to the primary of a small, low-power transformer, and the secondary voltage that results from the primary excitation is used (with or without rectification, amplification, or other modification) to trigger the thyristor switch. In this type, the degree of input-output isolation depends on the design of the transformer.
- Photo-coupled SSR's, in which the control signal is applied to a light or infrared source (usually, a light-emitting diode, or LED), and the radiation from that source is detected in a photosensitive semi-conductor (i.e., a photosensitive diode, a photo-sensitive transistor, or a photo-sensitive thyristor). The output of the photo-sensitive device is then used to trigger (gate) the TRIAC or the SCR's that switch the load current. Clearly, the only significant “coupling path” between input and output is the beam of light or infrared radiation, and electrical isolation is excellent. These SSR's are also referred to as “optically coupled” or “photo-isolated”.

Technical References

Thermocouples Reference Data (ITS90) mV v/s Temperature (Standard : ASTM E230-03)

		TYPE 'T' Cu-CuNi	TYPE 'E' NiCr-CuNi	TYPE 'J' Fe-CuNi	TYPE 'K' NiCr-NiAl	TYPE 'N' NiCrSi-NiSi	TYPE 'S' PtRh10%-Pt	TYPE 'R' PtRh13%-Pt	TYPE 'B' PtRh30%-PtRh6%
Tolerance	Standard	±0°C or ±0.75%	±1.7°C or ±0.5%	±2.2°C or ±75%	±2.2°C or ±75%	±2.2°C or ±75%	±1.5°C or ±25%	±1.5°C or ±25%	±0.5°C Over 800°C
	Special	±0.5°C or ±0.4%	±1°C or ±0.4%	±1.1°C or ±0.4%	±1.1°C or ±0.4%	±1.1°C or ±0.4%	±6°C or ±0.1%	±6°C or ±0.1%	±0.25°C Over 800°C
TEMPERATURE°C	-100	-3.379	-5.237	-4.633	-3.554	-2.407	-	-	-
	0	0	0	0	0	0	0	0	0
	100	4.279	6.319	5.269	4.096	2.774	0.646	0.647	0.033
	200	9.228	13.421	10.799	8.138	5.913	1.441	1.469	0.178
	300	14.862	21.036	16.327	12.209	9.341	2.323	2.401	0.431
	400	20.872	28.946	21.848	16.397	12.974	3.259	3.408	0.787
	500		37.005	27.393	20.644	16.748	4.233	4.471	1.242
	600		45.093	33.102	24.905	20.613	5.239	5.583	1.792
	700			39.132	29.129	24.527	6.275	6.743	2.431
	800			45.494	33.275	28.455	7.345	7.95	3.154
	900				37.326	32.371	8.449	9.208	3.957
	1000				41.276	36.256	9.587	10.506	4.834
	1100				45.119	40.087	10.757	11.85	5.78
	1200				48.838	43.846	11.951	13.228	6.786
	1250				50.644	45.694	12.554	13.926	7.311
	1300				52.41	47.513	13.159	14.629	7.848
	1400						14.373	16.04	8.956
	1500						15.582	17.451	10.099
	1600								11.263
	1700								12.433

Tolerence Value of RTD Pt-100 (IEC-775:1983)

Temperature °C	1/10 Din (±°C)	1/5 Din (±°C)	1/3 Din (±°C)	Class A (±°C)	Class B (±°C)
-100	0.080	0.160	0.267	0.350	0.800
-50	0.055	0.110	0.183	0.250	0.550
0	0.030	0.060	0.100	0.150	0.300
50	0.055	0.110	0.183	0.250	0.550
100	0.080	0.160	0.267	0.350	0.800
150	0.105	0.210	0.350	0.450	1.050
200	0.130	0.260	0.433	0.550	1.300
250	0.155	0.310	0.517	0.650	1.550
300	0.180	0.360	0.600	0.750	1.800
350	0.205	0.410	0.683	0.850	2.050
400	0.230	0.460	0.767	0.950	2.300

Industrial Platinum Resistance Thermometer Sensors

R(0) = 100.00 OHMS α = 3850

°C ITS90	0.00	-1.00	-2.00	-3.00	-4.00	-5.00	-6.00	-7.00	-8.00	-9.00	°C ITS90
-200	18.52										**-200**
-190	22.83	22.40	21.97	21.54	21.11	20.68	20.25	19.82	19.38	18.95	**-190**
-180	27.10	26.67	26.24	25.82	25.39	24.97	24.54	24.11	23.68	23.25	**-180**
-170	31.34	30.91	30.49	30.07	29.64	29.22	28.80	28.37	27.95	27.52	**-170**
-160	35.54	35.12	34.70	34.28	33.96	33.44	33.02	32.60	32.18	31.76	**-160**
-150	39.72	39.31	38.89	38.47	38.05	37.64	37.22	36.80	36.38	35.96	**-150**
-140	43.88	43.46	43.05	42.63	42.22	41.80	41.39	40.97	40.56	40.14	**-140**
-130	48.00	47.59	47.18	46.77	46.36	45.94	45.53	45.12	44.70	44.29	**-130**
-120	52.11	51.70	51.29	50.88	50.47	50.06	49.65	49.24	48.83	48.42	**-120**
-110	56.19	55.79	55.38	54.97	54.56	54.15	53.75	53.34	52.93	52.52	**-110**
-100	60.26	59.85	59.44	59.04	58.63	58.23	57.82	57.41	57.01	56.60	**-100**
-90	64.30	63.90	63.49	63.09	62.68	62.28	61.88	61.47	61.07	60.66	**-90**
-80	68.33	67.92	67.52	67.12	66.72	66.31	65.91	65.51	65.11	64.70	**-80**
-70	72.33	71.93	71.53	71.13	70.73	70.33	69.93	69.53	69.13	68.73	**-70**
-60	76.33	75.93	75.53	75.13	74.73	74.33	73.93	73.53	73.13	72.73	**-60**
-50	80.31	79.91	79.51	79.11	78.72	78.32	77.92	77.52	77.12	76.73	**-50**
-40	84.27	83.87	83.48	83.08	82.69	82.29	81.89	81.50	81.10	80.70	**-40**
-30-	88.22	87.83	87.43	87.04	86.64	86.25	85.85	85.46	85.06	84.67	**-30**
-20	92.16	91.77	91.37	90.98	90.59	90.19	89.80	89.40	89.01	88.62	**-20**
-10	96.09	95.69	95.30	94.91	94.52	94.12	93.73	93.34	92.95	92.55	**-10**
0	100.00	99.61	99.22	98.83	98.44	98.04	97.65	97.26	96.87	96.48	**0**

°C ITS90	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	°C ITS90
0	100.00	100.39	100.78	101.17	101.56	101.95	102.34	102.73	103.12	103.51	**0**
10	103.90	104.29	104.68	105.07	105.46	105.85	106.24	106.63	107.02	107.40	**10**
20	107.79	108.18	108.57	108.96	109.35	109.73	110.12	110.51	110.90	111.29	**20**
30	111.67	112.06	112.45	112.83	113.22	113.61	114.00	114.38	114.77	115.15	**30**
40	115.54	115.93	116.31	116.70	117.08	117.47	117.86	118.24	118.63	119.01	**40**
50	119.40	119.78	120.17	120.55	120.94	121.32	121.71	122.09	122.47	122.86	**50**
60	123.24	123.63	124.01	124.39	124.78	125.16	125.54	125.93	126.31	126.69	**60**
70	127.08	127.46	127.84	128.22	128.61	128.99	129.37	129.75	130.13	130.52	**70**
80	130.90	131.28	131.66	132.04	132.42	132.80	133.18	133.57	133.95	134.33	**80**
90	134.71	135.09	135.47	135.85	136.23	136.61	136.99	137.37	137.75	138.13	**90**
100	138.51	138.88	139.26	139.64	140.02	140.40	140.56	141.16	141.54	141.91	**100**
110	142.29	142.67	143.05	143.43	143.80	144.18	144.56	144.94	145.31	145.69	**110**
120	146.07	146.44	146.82	147.20	147.57	147.95	148.33	148.70	149.08	149.46	**120**
130	149.83	150.21	150.58	150.96	151.33	151.71	152.08	152.46	152.83	153.21	**130**
140	153.58	153.96	154.33	154.71	155.08	155.46	155.83	156.20	156.58	156.95	**140**
150	157.33	157.70	158.07	158.45	158.82	159.19	159.56	159.94	160.31	160.68	**150**
160	161.05	161.43	161.80	162.17	162.54	162.91	163.29	163.66	164.03	164.40	**160**
170	164.77	165.14	165.51	165.89	166.26	166.63	167.00	167.37	167.74	168.11	**170**
180	168.48	168.85	169.22	169.59	169.96	170.33	170.70	171.07	171.43	171.80	**180**
190	172.17	172.54	172.91	173.28	173.65	174.02	174.38	174.75	175.12	175.49	**190**
200	175.86	176.22	176.59	176.96	177.33	177.69	178.06	178.43	178.79	179.16	**200**
210	179.53	179.89	180.26	180.63	180.99	181.36	181.72	182.09	182.46	182.82	**210**
220	183.19	183.55	183.92	184.28	184.65	185.01	185.38	185.74	186.11	186.47	**220**
230	186.84	187.20	187.56	187.93	188.29	188.66	189.02	189.38	189.75	190.11	**230**
240	190.47	190.84	191.20	191.56	191.92	192.29	192.65	193.01	193.37	193.74	**240**
250	194.10	194.46	194.82	195.18	195.55	195.91	196.27	196.63	196.99	197.35	**250**
260	197.71	198.07	198.43	198.79	199.15	199.51	199.87	200.23	200.59	200.95	**260**
270	210.31	201.67	202.03	202.39	202.75	203.11	203.47	203.83	204.19	204.55	**270**
280	204.90	205.26	205.62	205.98	206.34	206.70	207.05	207.41	207.77	208.13	**280**

Industrial Platinum Resistance Thermometer Sensors

R(0) = 100.00 OHMS α = 3850

°C ITS90	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	°C ITS90
290	208.48	208.84	209.20	209.56	209.91	210.27	210.63	210.98	211.34	211.70	**290**
300	212.05	212.41	212.76	213.12	213.48	213.83	214.19	214.54	214.90	215.25	**300**
310	215.61	215.96	216.32	216.67	217.03	217.38	217.74	218.09	218.44	218.80	**310**
320	219.15	219.51	219.86	220.21	220.57	220.92	221.27	221.63	221.98	222.33	**320**
330	222.68	223.04	223.39	223.74	224.09	224.45	224.80	225.15	225.50	225.85	**330**
340	226.21	226.56	226.91	227.26	227.61	227.96	228.31	228.66	229.02	229.37	**340**
350	229.72	230.07	230.42	230.77	231.12	231.47	231.82	232.17	232.52	232.87	**350**
360	233.21	233.56	233.91	234.26	234.61	234.96	235.31	235.66	236.00	236.35	**360**
370	236.70	237.05	237.40	237.74	238.09	238.44	238.79	239.13	239.48	239.48	**370**
380	240.18	240.52	240.87	241.22	241.56	241.91	242.26	242.60	242.95	243.29	**380**
390	243.64	243.99	244.33	244.68	245.02	245.37	245.71	246.06	246.40	246.75	**390**
400	247.09	247.44	247.78	248.13	248.47	248.81	249.16	249.50	249.85	250.19	**400**
410	250.53	250.88	251.22	251.56	251.91	252.25	252.59	252.93	253.28	253.62	**410**
420	253.96	254.30	254.65	254.99	255.33	255.67	256.01	256.35	256.70	257.04	**420**
430	257.38	257.72	258.06	258.40	258.74	259.08	259.42	259.76	260.10	260.44	**430**
440	260.78	261.12	261.46	261.80	262.14	262.48	262.82	263.16	263.50	263.84	**440**
450	264.18	264.52	264.86	265.20	265.53	265.87	266.21	266.55	266.89	267.22	**450**
460	267.56	267.90	268.24	268.57	268.91	269.25	269.59	269.92	270.26	270.60	**460**
470	270.93	271.27	271.61	271.94	272.28	272.61	272.95	273.29	273.62	273.96	**470**
480	274.29	274.63	274.96	275.30	275.63	275.97	276.30	276.64	276.97	277.31	**480**
490	277.64	277.98	278.31	278.64	278.98	279.31	279.64	279.98	280.31	280.64	**490**
500	280.98	281.31	281.64	281.98	282.31	282.64	282.97	283.31	283.64	283.97	**500**
510	284.30	284.63	284.97	285.30	285.63	285.96	286.29	286.62	286.95	287.29	**510**
520	287.62	287.63	288.82	288.61	288.94	289.27	289.60	289.93	290.26	290.59	**520**
530	290.92	291.25	291.58	291.91	292.24	292.56	292.89	293.22	293.55	293.88	**530**
540	294.21	294.54	294.86	295.19	295.52	295.85	296.18	296.50	296.83	297.16	**540**
550	297.49	297.81	298.14	298.47	298.80	299.12	299.45	299.78	300.10	300.43	**550**
560	300.75	301.08	301.41	301.73	302.06	302.38	302.71	303.03	303.36	303.69	**560**
570	304.01	304.34	304.66	304.98	305.31	305.63	305.96	306.28	306.61	306.93	**570**
580	307.25	307.58	307.90	308.23	308.55	308.87	309.20	309.52	309.84	310.16	**580**
590	310.49	310.81	311.13	311.45	311.78	312.10	312.42	312.74	313.06	313.39	**590**
600	313.71	314.03	314.35	314.67	314.99	315.31	315.64	315.96	316.28	316.60	**600**
610	316.92	317.24	317.56	317.88	318.20	318.52	318.84	319.16	319.48	319.80	**610**
620	320.12	320.43	320.75	321.07	321.39	321.71	322.03	322.35	322.67	322.98	**620**
630	323.30	323.62	323.94	324.26	324.57	324.89	325.21	325.53	325.84	326.16	**630**
640	326.48	326.79	327.11	327.43	327.74	328.06	328.38	328.69	329.01	329.32	**640**
650	329.64	329.96	330.27	330.59	330.90	331.22	331.53	331.85	332.16	332.48	**650**
660	332.79	333.11	333.42	333.74	334.05	334.36	334.68	334.99	335.31	335.62	**660**
670	335.93	336.25	336.56	336.87	337.18	337.50	337.81	338.12	338.44	338.75	**670**
680	339.06	339.37	339.69	340.00	340.31	340.62	340.93	341.24	341.56	341.87	**680**
690	342.18	342.49	342.80	343.11	343.42	343.73	344.04	344.35	344.66	344.97	**690**
700	345.28	345.59	345.90	346.21	346.52	346.83	347.14	347.45	347.76	348.07	**700**
710	348.38	348.69	348.99	349.30	349.61	349.92	350.23	350.54	350.84	351.15	**710**
720	351.46	351.77	352.08	352.38	352.69	353.00	353.30	353.61	353.92	354.22	**720**
730	354.53	354.84	355.14	355.45	355.76	356.06	356.37	356.67	356.98	357.28	**730**
740	357.59	357.90	358.20	358.57	358.81	359.12	359.42	359.72	360.03	360.33	**740**
750	360.64	360.94	361.25	361.55	361.85	362.16	362.46	362.76	363.07	363.37	**750**
760	363.67	363.98	364.28	364.58	364.89	365.19	365.49	365.79	366.10	366.40	**760**
770	366.70	367.00	367.30	367.60	367.91	368.21	368.51	368.81	369.11	369.41	**770**
780	369.71	370.01	370.31	370.61	370.91	371.21	371.51	371.81	372.11	372.41	**780**
790	372.71	373.01	373.31	373.61	373.91	374.21	374.51	374.81	375.11	375.41	**790**
800	375.70	376.00	376.30	376.60	376.90	377.19	377.49	377.79	378.09	378.39	**800**
810	378.68	378.98	379.28	379.57	379.87	380.17	380.46	380.76	381.06	381.35	**810**
820	381.65	381.95	382.24	382.54	382.83	383.13	383.42	383.72	384.01	384.31	**820**
830	384.60	384.90	385.19	385.49	385.78	386.08	386.37	386.67	386.96	387.25	**830**
840	387.55	387.84	388.14	388.43	388.72	389.02	389.31	389.60	389.90	390.19	**840**
850	390.48										**850**

Type S Thermocouple Table

Platinum - 10% Rhodium/Platinum, Electromotive Force as a function of Temperature, E/µV
As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
0	0	5	11	16	22	27	33	38	44	50	**0**
10	55	61	67	72	78	84	90	95	101	107	**10**
20	113	119	125	131	137	143	149	155	161	167	**20**
30	173	179	185	191	197	204	210	216	222	229	**30**
40	235	241	248	254	260	267	273	280	286	292	**40**
50	299	305	312	319	325	332	338	345	352	358	**50**
60	365	372	378	385	392	399	405	412	419	426	**60**
70	433	440	446	453	460	467	474	481	488	495	**70**
80	502	509	516	523	530	538	545	552	559	566	**80**
90	573	580	588	595	602	609	617	624	631	639	**90**
100	646	653	661	668	675	683	690	698	705	713	**100**
110	720	727	735	743	750	758	765	773	780	788	**110**
120	795	803	811	818	826	834	841	849	857	865	**120**
130	872	880	888	896	903	911	919	927	935	942	**130**
140	950	958	966	974	982	990	998	1006	1013	1021	**140**
150	1029	1037	1045	1053	1061	1069	1077	1085	1094	1102	**150**
160	1110	1118	1126	1134	1142	1150	1158	1167	1175	1183	**160**
170	1191	1199	1207	1216	1224	1232	1240	1249	1257	1265	**170**
180	1273	1282	1290	1298	1307	1315	1323	1332	1340	1348	**180**
190	1357	1365	1373	1382	1390	1399	1407	1415	1424	1432	**190**
200	1441	1449	1458	1466	1475	1483	1492	1500	1509	1517	**200**
210	1526	1534	1543	1551	1560	1569	1577	1586	1594	1603	**210**
220	1612	1620	1629	1638	1646	1655	1663	1672	1681	1690	**220**
230	1698	1707	1716	1724	1733	1742	1751	1759	1768	1777	**230**
240	1786	1794	1803	1812	1821	1829	1838	1847	1856	1865	**240**
250	1874	1882	1891	1900	1909	1918	1927	1936	1944	1953	**250**
260	1962	1971	1980	1989	1998	2007	2016	2025	2034	2043	**260**
270	2052	2061	2070	2078	2087	2096	2105	2114	2123	2132	**270**
280	2141	2151	2160	2169	2178	2187	2196	2205	2214	2223	**280**
290	2232	2241	2250	2259	2268	2277	2287	2296	2305	2314	**290**
300	2323	2332	2341	2350	2360	2369	2378	2387	2396	2405	**300**
310	2415	2424	2433	2442	2451	2461	2470	2479	2488	2497	**310**
320	2507	2516	2525	2534	2544	2553	2562	2571	2581	2590	**320**
330	2599	2609	2618	2627	2636	2646	2655	2664	2674	2683	**330**
340	2692	2702	2711	2720	2730	2739	2748	2758	2767	2776	**340**
350	2786	2795	2805	2814	2823	2833	2842	2851	2861	2870	**350**
360	2880	2889	2899	2908	2917	2927	2936	2946	2955	2965	**360**
370	2974	2983	2993	3002	3012	3021	3031	3040	3050	3059	**370**
380	3069	3078	3088	3097	3107	3116	3126	3135	3145	3154	**380**
390	3164	3173	3183	3192	3202	3212	3221	3231	3240	3250	**390**
400	3259	3269	3279	3288	3298	3307	3317	3326	3336	3346	**400**
410	3355	3365	3374	3384	3394	3403	3413	3423	3432	3442	**410**
420	3451	3461	3471	3480	3490	3500	3509	3519	3529	3538	**420**
430	3548	3558	3567	3577	3587	3596	3606	3616	3626	3635	**430**
440	3645	3655	3664	3674	3684	3694	3703	3713	3123	3732	**440**
450	3742	3752	3762	3771	3781	3791	3801	3810	3820	3830	**450**
460	3840	3850	3859	3869	3879	3889	3898	3908	3918	3928	**460**
470	3938	3947	3957	3967	3977	3987	3997	4006	4016	4026	**470**
480	4036	4046	4056	4065	4075	4085	4095	4105	4115	4125	**480**
490	4134	4144	4154	4164	4174	4184	4194	4204	4213	4223	**490**
500	4233	4243	4253	4263	4273	4283	4293	4303	4313	4323	**500**

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As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
510	4332	4342	4352	4362	4372	4382	4392	4402	4412	4422	**510**
520	4432	4442	4452	4462	4472	4482	4492	4502	4512	4522	**520**
530	4532	4542	4552	4562	4572	4582	4592	4602	4612	4622	**530**
540	4632	4642	4652	4662	4672	4682	4692	4702	4712	4122	**540**
550	4732	4742	4752	4762	4772	4782	4793	4803	4813	4823	**550**
560	4833	4843	4853	4863	4873	4883	4893	4904	4914	4924	**560**
570	4934	4344	4954	4964	4974	4984	4995	5005	5015	5025	**570**
580	5035	5045	5055	5066	5076	5086	5096	5106	5116	5127	**580**
590	5137	5147	5157	5167	5178	5188	5198	5208	5218	5228	**590**
600	5239	5249	5259	5269	5280	5290	5300	5310	5320	5331	**600**
610	5341	5351	5361	5372	5382	5392	5402	5413	5423	5433	**610**
620	5443	5454	5464	5474	5485	5495	5505	5515	5526	5536	**620**
630	5546	5557	5567	5577	5588	5598	5608	5618	5629	5639	**630**
640	5649	5660	5670	5680	5691	5701	5712	5722	5732	5743	**640**
650	5753	5763	5774	5784	5794	5805	5815	5826	5836	5846	**650**
660	5857	5867	5878	5888	5898	5909	5919	5930	5940	5950	**660**
670	5961	5971	5982	5992	6003	6013	6024	6034	6044	6055	**670**
680	6065	6076	6056	6097	6107	6118	6128	6139	6149	6160	**680**
690	6170	6181	6191	6202	6212	6223	6233	6244	6254	6265	**690**
700	6275	6286	6296	6307	6317	6328	6338	6349	6360	6370	**700**
710	6381	6391	6402	6412	6423	6434	6444	6455	6465	6476	**710**
720	6486	6497	6508	6518	6529	6539	6550	6561	6571	6582	**720**
730	6593	6603	6614	6624	6635	6646	6656	6667	6678	6688	**730**
740	6699	6710	6720	6731	6742	6752	6763	6774	6784	6795	**740**
750	6806	6817	6827	6838	6849	6859	6870	6881	6892	6902	**750**
760	6913	6924	6934	6945	6956	6967	6977	6988	6999	7010	**760**
770	7020	7031	7042	7053	7064	7074	7085	7096	7104	7117	**770**
780	7128	7139	7150	7161	7172	7182	7193	7204	7215	7226	**780**
790	7236	7247	7258	7269	7280	7291	7302	7312	7323	7334	**790**
800	7345	7356	7367	7378	7388	7399	7410	7421	7432	7443	**800**
810	7454	7465	7476	7487	7497	7508	7519	7530	7541	7552	**810**
820	7563	7574	7585	7596	7607	7618	7629	7640	7651	7662	**820**
830	7673	7684	7695	7706	7717	7728	7739	7750	7761	7772	**830**
840	7783	7794	7805	7816	7827	7838	7849	7860	7871	7882	**840**
850	7893	7904	7915	7926	7937	7948	7959	7970	7981	7992	**850**
860	8003	8014	8026	8037	8048	8059	8070	8081	8092	8103	**860**
870	8114	8125	8197	8148	8159	8170	8181	8192	8203	8214	**870**
880	8226	8237	8248	8259	8270	8281	8293	8304	8315	8326	**880**
890	8337	8348	8360	8371	8382	8393	8404	8416	8427	8438	**890**
900	8449	8460	8472	8483	8494	8505	8517	8528	8539	8550	**900**
910	8562	8573	8584	8595	8607	8618	8629	8640	8652	8663	**910**
920	8674	8685	8697	8708	8719	8731	8742	8753	8765	8776	**920**
930	8787	8798	8810	8821	8832	8844	8855	8866	8878	8889	**930**
940	8900	8912	8923	8935	8946	8957	8969	8980	8991	9003	**940**
950	9014	9025	9037	9048	9060	9071	9082	9094	9105	9117	**950**
960	9128	9139	9151	9162	9174	9185	9197	9208	9219	9231	**960**
970	9242	9254	9265	9277	9288	9300	9311	9323	9334	9345	**970**
980	9357	9368	9380	9391	9403	9414	9426	9437	9449	9460	**980**
990	9472	9483	9495	9506	9518	9529	9541	9552	9564	9576	**990**
1000	9587	9599	9610	9622	9633	9645	9656	9668	9680	9610	**1000**
1010	9703	9714	9726	9737	9749	9761	9772	9784	9795	9807	**1010**
1020	9819	9830	9842	9853	9865	9877	9888	9900	9911	9923	**1020**
1030	9935	9946	9958	9970	9981	9993	10005	10016	10028	10040	**1030**
1040	10051	10063	10075	10086	10098	10110	10121	10133	10145	10156	**1040**
1050	10168	10180	10191	10203	10215	10227	10238	10250	10262	10273	**1050**

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t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
1060	10285	10297	10309	10320	10332	10344	10356	10367	10379	10391	**1060**
1070	10403	10414	10426	10438	10450	10461	10473	10485	10497	10509	**1070**
1080	10520	10532	10544	10556	10567	10579	10591	10603	10615	10626	**1080**
1090	10638	10650	10662	10674	40686	10697	10709	10721	10733	10745	**1090**
1100	10757	10768	10780	10792	10804	10816	10828	10839	10851	10863	**1100**
1110	10875	10887	70899	10911	10922	10934	10946	10958	10970	10982	**1110**
1120	10994	11006	11017	11029	11041	11053	11065	11077	11089	11101	**1120**
1130	11113	11125	11136	11148	11160	11172	11184	11196	11208	11220	**1130**
1140	11232	11244	11256	11268	11280	11291	11303	11315	11327	11339	**1140**
1150	11351	11363	11375	11387	11399	11411	11423	11435	11447	11459	**1150**
1160	11471	11483	11495	11507	11519	11531	111542	11554	11566	11578	**1160**
1170	11590	11602	11614	11626	11638	11650	11662	11674	11686	11698	**1170**
1180	11710	11722	11734	11746	11758	11770	11782	11794	11806	11818	**1180**
1190	11830	11842	11854	11866	11878	11890	11902	11914	11926	11939	**1190**
1200	11951	11963	11975	11987	11999	12011	12023	12035	12047	12059	**1200**
1210	12071	12083	12095	12107	12119	12131	12143	12155	12167	12179	**1210**
1220	12191	12203	12216	12228	12240	12252	12264	12276	12288	12300	**1220**
1230	12312	12324	12336	12348	12360	12372	12384	12397	12409	12421	**1230**
1240	12433	12445	12457	12469	12481	12493	12505	12517	12529	12542	**1240**
1250	12554	12566	12578	12590	12602	12614	12626	12638	12650	12662	**1250**
1260	12675	12687	12699	12711	12723	12735	12747	12759	12771	12783	**1260**
1270	12796	12808	12820	12832	12844	12856	12868	12880	12892	12905	**1270**
1280	12917	12929	12941	12953	12965	12977	12989	13001	13014	13026	**1280**
1290	13038	13050	13062	13074	13086	13098	13111	13123	13135	13147	**1290**
1300	13159	13171	13183	13195	13208	13220	13232	13244	13256	13268	**1300**
1310	13280	13292	13305	13317	13329	13341	13353	13365	13377	13390	**1310**
1320	13402	13414	13426	13438	13450	13462	13474	13487	13499	13511	**1320**
1330	13523	13535	13547	13559	19572	13584	13596	13608	13620	13632	**1330**
1340	13644	13657	13669	13681	13693	13705	13717	13729	13742	13754	**1340**
1350	13766	13778	13790	13802	13814	13826	13839	13851	13863	13875	**1350**
1360	13887	13899	13911	13924	13936	13948	13960	13972	13984	13996	**1360**
1370	14009	14021	14033	14045	14057	14069	14081	14094	14106	14118	**1370**
1380	14130	14142	14154	14166	14178	14191	14203	14215	14227	14239	**1380**
1390	14251	14263	14276	14288	14300	14312	14324	14336	14348	14360	**1390**
1400	14373	14385	14397	14409	14421	14433	14445	14457	14470	14482	**1400**
1410	14494	14506	14518	14530	14542	14554	14567	14579	14591	14603	**1410**
1420	14615	14627	14639	14651	14664	14676	14688	14700	14712	14724	**1420**
1430	14736	14748	14760	14773	14785	14797	14809	14821	14833	14845	**1430**
1440	14857	14869	14881	14894	14906	14918	14930	14942	14954	14966	**1440**
1450	14978	14990	15002	15015	15027	15039	15051	15063	15075	15087	**1450**
1460	15099	15111	15123	15135	15148	15160	15172	15184	15196	15208	**1460**
1470	15220	15232	15244	15256	15268	15280	15292	15304	15317	15329	**1470**
1480	15341	15353	15365	15377	15389	15401	15413	15425	15437	15449	**1480**
1490	15461	15473	15485	15497	15509	15521	15534	15546	15558	15570	**1490**
1500	15582	15594	15606	15618	15630	15642	15654	15666	15678	15690	**1500**
1510	15702	15714	15726	15738	15750	15762	15774	15786	15798	15810	**1510**
1520	15822	15834	15846	15858	15870	15882	15894	15906	15918	15930	**1520**
1530	15942	15954	15966	15978	15990	16002	16014	16026	16038	16050	**1530**
1540	16062	16074	16086	16098	16110	16122	16134	16146	16158	16170	**1540**
1550	16182	16194	16205	16217	16229	16241	16253	16265	16277	16289	**1550**
1560	16301	16313	16325	16337	16349	16361	16373	16385	16396	16408	**1560**
1570	16420	16432	16444	16456	16468	16480	16492	16504	16516	16527	**1570**
1580	16539	16551	16563	16575	16587	16599	16611	16623	16634	16646	**1580**
1590	16658	16670	16682	16694	16706	16718	16729	16741	16753	16765	**1590**
1600	16777	16789	16801	16812	16824	16836	16848	16860	16872	16883	**1600**

Type S Thermocouple Table

Platinum - 10% Rhodium/Platinum, Electromotive Force as a function of Temperature, E/µV
As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
1610	16895	16907	16919	16931	16943	16954	16966	16978	16990	17002	**1610**
1620	17013	17025	17037	17049	17061	17072	17084	17096	17108	17120	**1620**
1630	17131	17143	17155	17167	17178	17190	17202	17214	17225	17237	**1630**
1640	17249	17261	17272	17284	17296	17308	17319	17331	17343	17355	**1640**
1650	17366	17378	17390	17401	17413	17425	17437	17448	17460	17472	**1650**
1660	17483	17495	17507	17518	17530	17542	17553	17565	17577	17588	**1660**
1670	17600	17612	17623	17635	17647	17658	17670	17682	17693	17705	**1670**
1680	17717	17728	17740	17751	17763	17775	17786	17798	17809	17821	**1680**
1690	17232	17844	17855	17867	17878	17890	17901	17913	17924	17936	**1690**
1700	17947	17959	17970	17982	17993	18004	18016	18027	18039	18050	**1700**
1710	18061	18073	18084	18095	18107	18118	18129	18140	18152	18163	**1710**
1720	18174	18185	18196	18208	18219	18230	18241	18252	18263	18274	**1720**
1730	18285	18297	18308	18319	18330	18341	18352	18362	18373	18384	**1730**
1740	18395	18406	18417	18428	18439	18449	18460	18471	18482	18493	**1740**
1750	18503	18514	18525	18535	18546	18557	18567	18578	18588	18599	**1750**
1760	18609	18620	18630	18641	18651	18661	18672	18682	18693		**1760**

Type R Thermocouple Table

Platinum - 13% Rhodium/Platinum, Electromotive Force as a function of Temperature, E/μV

As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
0	0	5	11	16	21	27	32	38	43	49	**0**
10	54	60	65	71	77	82	88	94	100	105	**10**
20	111	117	123	129	135	141	147	153	159	165	**20**
30	171	177	183	189	195	201	207	214	220	226	**30**
40	232	239	245	251	258	264	271	277	284	290	**40**
50	296	303	310	316	323	329	336	343	349	356	**50**
60	363	369	376	383	390	397	403	410	417	424	**60**
70	431	438	445	452	459	466	473	480	487	494	**70**
80	501	508	516	523	530	537	544	552	559	566	**80**
90	573	581	588	595	603	610	618	625	632	640	**90**
100	647	655	662	670	677	685	693	700	708	715	**100**
110	723	731	738	746	754	761	769	777	785	792	**110**
120	800	808	816	824	832	839	847	855	863	871	**120**
130	879	887	895	903	911	919	927	935	943	951	**130**
140	959	967	976	984	992	1000	1008	1016	1025	1033	**140**
150	1041	1049	1058	1066	1074	1082	1091	1099	1107	1116	**150**
160	1124	1132	1141	1149	1158	1166	1175	1183	1191	1200	**160**
170	1208	1217	1225	1234	1242	1251	1260	1268	1277	1285	**170**
180	1294	1303	1311	1320	1329	1337	1346	1355	1363	1372	**180**
190	1381	1389	1398	1407	1416	1425	1433	1442	1451	1460	**190**
200	1469	1477	1486	1495	1504	1513	1522	1531	1540	1549	**200**
210	1558	1567	1575	1584	1593	1602	1611	1620	1629	1639	**210**
220	1648	1657	1666	1675	1684	1693	1702	1711	1720	1729	**220**
230	1739	1748	1757	1766	1775	1784	1794	1803	1812	1821	**230**
240	1831	1840	1849	1858	1868	1877	1886	1895	1905	1914	**240**
250	1923	1933	1942	1951	1961	1970	1980	1989	1998	2008	**250**
260	2017	2027	2036	2046	2055	2064	8074	2083	2093	2102	**260**
270	2112	2121	2131	2146	2150	2159	2169	2179	2188	2198	**270**
280	2207	2217	2226	2236	2246	2255	2265	2275	2284	2294	**280**
290	2304	2313	2323	2333	2342	2352	2362	2371	2381	2391	**290**
300	2401	2410	2420	2430	2440	2449	2459	2469	2479	2488	**300**
310	2498	2508	2518	2528	2538	2547	2557	2567	2577	2587	**310**
320	2597	2607	2617	2626	2636	2646	2656	2666	2676	2686	**320**
330	2696	2706	2716	2726	2736	2746	2756	2766	2776	2786	**330**
340	2796	2806	2816	2826	2836	2846	2856	2866	2876	2886	**340**
350	2896	2906	2916	2926	2937	2947	2957	2967	2977	2987	**350**
360	2997	3007	3018	3028	3038	3048	3058	3068	3079	3089	**360**
370	3099	3109	3119	3130	3140	3150	3160	3171	3181	3191	**370**
380	3201	3212	3222	3232	3242	3259	3263	3273	3284	3294	**380**
390	3304	3315	3325	3335	3346	3356	3366	3377	3387	3397	**390**
400	3408	3418	3428	3439	3449	3460	3470	3480	3491	3501	**400**
410	3512	3522	3533	3543	3553	3564	3574	3585	3595	3606	**410**
420	3616	3627	3637	3648	3658	3669	3679	3690	3700	3711	**420**
430	3721	3732	3742	3753	3764	3774	3785	3795	3806	3816	**430**
440	3827	3838	3848	3859	3869	3880	3891	3901	3912	3922	**440**
450	3933	3944	3954	3965	3976	3986	3997	4008	4018	4029	**450**
460	4040	4050	4061	4072	4083	4093	4104	4115	4125	4136	**460**
470	4147	4158	4168	4179	4190	4201	4211	4222	4233	4244	**470**
480	4255	4265	4276	4287	4298	4309	4319	4330	4341	4352	**480**
490	4363	4373	4384	4395	4406	4417	4428	4439	4449	4460	**490**
500	4471	4482	4493	4504	4515	4526	4537	4548	4558	4569	**500**
510	4580	4591	4602	4613	4624	4635	4646	4657	4668	4679	**510**

Type R Thermocouple Table

Platinum - 13% Rhodium/Platinum, Electromotive Force as a function of Temperature, E/µV
As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
520	4690	4701	4712	4723	4734	4745	4756	4767	4778	4789	**520**
530	4800	4811	4822	4833	4844	4855	4866	4877	4888	4899	**530**
540	4910	4922	4933	4944	4955	4366	4977	4988	4999	5010	**540**
550	5021	5033	5044	5055	5066	5077	5088	5099	5111	5122	**550**
560	5133	5144	5155	5166	5178	5189	5200	5211	5222	5234	**560**
570	5245	5256	5267	5279	5290	5301	5312	5323	5335	5346	**570**
580	5357	5369	5380	5391	5402	5414	5425	5436	5448	5459	**580**
590	5470	5481	5493	5504	5515	5527	5538	5549	5561	5572	**590**
600	5583	5595	5606	5618	5629	5640	5652	5663	5674	5686	**600**
610	5697	5709	5720	5731	5743	5754	5766	5777	5789	5800	**610**
620	5812	5823	5834	5846	5857	5869	5880	5892	5903	5915	**620**
630	5926	5938	5949	5961	5972	5984	5995	6007	6018	6030	**630**
640	6041	6053	6065	6076	6088	6099	6111	6122	6134	6146	**640**
650	6157	6169	6180	6192	6204	6215	6227	6238	6250	6262	**650**
660	6273	6285	6297	6308	6320	6332	6343	6355	6367	6378	**660**
670	6390	6402	6413	6425	6437	6448	6460	6472	6484	6495	**670**
680	6507	6519	6531	6542	6554	6566	6578	6589	6601	6613	**680**
690	6625	6636	6648	6660	6672	6684	6695	6707	6719	6731	**690**
700	6743	6755	6766	6778	6790	6802	6814	6826	6838	6849	**700**
710	6861	6873	6885	6897	6909	6921	6933	6945	6956	6968	**710**
720	6980	6992	7004	7016	7028	7040	7052	7064	7076	7088	**720**
730	7100	7112	7124	7136	7148	7160	7172	7184	7196	7208	**730**
740	7220	7232	7244	7256	7268	7280	7292	7304	7316	7928	**740**
750	7340	7352	7364	7376	7389	7401	7413	7425	7437	7449	**750**
760	7461	7473	7485	7498	7510	7522	7534	7546	7558	7570	**760**
770	7583	7595	7607	7619	7631	7644	7656	7668	7680	7692	**770**
780	7705	7717	7729	7741	7753	7766	7778	7790	7802	7815	**780**
790	7827	7839	7851	7864	7876	7888	7901	7913	7925	7938	**790**
800	7950	7962	7974	7987	7999	8011	8024	8036	8048	8061	**800**
810	8073	8086	8098	8110	8123	8135	8147	8160	8172	8185	**810**
820	8197	8209	8222	8234	8247	8259	8272	8284	8296	8309	**820**
830	8321	8334	8346	8359	8371	8384	8396	8409	8421	8434	**830**
840	8446	8459	8471	8484	8496	8509	8521	8534	8546	8559	**840**
850	8571	8584	8597	8609	8622	8634	8647	8659	8672	8685	**850**
860	8697	8710	8722	8735	8748	8760	8773	8785	8798	8811	**860**
870	8823	8836	8849	8861	8874	8887	8899	8912	8925	8937	**870**
880	8950	8963	8975	8388	9001	9014	9026	9039	9052	9065	**880**
890	9077	9090	9103	9115	9128	9141	9154	9167	9179	9192	**890**
900	9205	9218	9230	9243	9256	9269	9282	9294	9307	9320	**900**
910	9333	9346	9359	9371	9384	9397	9410	9423	9436	9449	**910**
920	9461	9474	9487	9500	9513	9526	9539	9552	9565	9578	**920**
930	9590	9603	9616	9629	9642	9655	9668	9681	9694	9707	**930**
940	9720	9733	9746	9759	9772	9785	9798	9811	9824	9837	**940**
950	9850	9863	9876	9889	9902	9915	9928	9941	9954	9967	**950**
960	9980	9993	10006	10019	10032	10046	10059	10072	10085	10098	**960**
970	10111	10124	10137	10150	10163	10177	10190	10203	10216	10229	**970**
980	10242	10255	10268	10282	10295	10308	10321	10334	10347	10361	**980**
990	10374	10387	10400	10413	10427	10440	10453	10466	10480	10493	**990**
1000	10506	10519	10532	10546	10559	10572	10585	10599	10612	10625	**1000**
1010	10638	10652	10665	10678	10692	10705	10718	10731	10745	10758	**1010**
1020	10771	10785	10798	10811	10825	10838	10851	10865	10878	10891	**1020**
1030	10905	10918	10932	10945	10958	10972	10985	10998	11012	11025	**1030**
1040	11039	11052	11065	11079	11092	11106	11119	11132	11146	11159	**1040**
1050	11173	11186	11200	11213	11227	11240	11253	11267	11280	11294	**1050**
1060	11307	11321	11334	11348	11361	11375	11388	11402	11415	11429	**1060**

Type R Thermocouple Table

Platinum - 13% Rhodium/Platinum, Electromotive Force as a function of Temperature, E/µV
As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
1070	11442	11456	11469	11483	11496	11510	11524	11537	11551	11564	**1070**
1080	11578	11591	11605	11618	11632	11646	11659	11673	11686	11700	**1080**
1090	11714	11727	11741	11754	11768	11782	11795	11809	11822	11836	**1090**
1100	11850	11863	11877	11891	11904	11918	11931	11945	11959	11972	**1100**
1110	11986	12000	12013	12027	12041	12054	12068	12082	12096	12109	**1110**
1120	12123	12137	12150	12164	12178	12191	12205	12219	12233	12246	**1120**
1130	12260	12274	12288	12301	12315	12329	12342	12356	12370	12384	**1130**
1140	12397	12411	12425	12439	12453	12466	12480	12494	12508	12521	**1140**
1150	12535	12549	12563	12577	12590	12604	12618	12632	12646	12659	**1150**
1160	12673	12687	12701	12715	12729	12742	12756	12770	12784	12798	**1160**
1170	12812	12825	12839	12853	12867	12881	12895	12909	12922	12936	**1170**
1180	12950	12964	12978	12992	13006	13019	13033	13047	13061	13075	**1180**
1190	13089	13103	13117	13131	13145	13158	13172	13186	13200	13214	**1190**
1200	13228	13242	13256	13270	13284	13298	13311	13325	13339	13353	**1200**
1210	13367	13381	13395	13409	13423	13437	13451	13465	13479	13493	**1210**
1220	13507	13521	13535	13549	13563	13577	13590	13604	13618	13632	**1220**
1230	13646	13660	13674	13688	13702	13716	13730	13744	13758	13772	**1230**
1240	13786	13800	13814	13828	13842	13856	13870	13884	13898	13912	**1240**
1250	13926	13940	13954	13968	13982	13996	14010	14024	14038	14052	**1250**
1260	14066	14081	14095	14109	14123	14137	14010	14165	14179	14193	**1260**
1270	14207	14221	14235	14249	14263	14277	14151	14305	14319	14333	**1270**
1280	14347	14361	14375	14390	14404	14418	14291	14446	14460	14474	**1280**
1290	14488	14502	14516	14530	14544	14558	14432	14586	14601	14615	**1290**
1300	14629	14643	14657	14671	14685	14699	14572	14727	14741	14755	**1300**
1310	14770	14784	14798	14812	14826	14840	14713	14868	14882	14896	**1310**
1320	14911	14925	14939	14953	14967	14981	14854	15009	15023	15037	**1320**
1330	15052	15066	15080	15094	15108	15122	14995	15150	15164	15179	**1330**
1340	15193	15207	15221	15235	15249	15263	15136	15291	15306	15320	**1340**
1350	15334	15348	15362	15376	15390	15404	15277	15433	15447	15461	**1350**
1360	15475	15489	15503	15517	15531	15546	15419	15574	15588	15602	**1360**
1370	15616	15630	15645	15659	15673	15687	15560	15715	15729	15743	**1370**
1380	15758	15772	15786	15800	15814	15828	15701	15856	15871	15885	**1380**
1390	15899	15913	15927	15941	15955	15969	15842	15998	16012	16026	**1390**
1400	16040	16054	16068	16082	16097	16111	16125	16139	16153	16167	**1400**
1410	16181	16196	16210	16224	16238	16252	16266	16280	16294	16309	**1410**
1420	16323	16337	16351	16365	16379	16393	16407	16422	16436	16450	**1420**
1430	16464	16478	16492	16506	16520	16534	16549	16563	16577	16591	**1430**
1440	16605	16619	16633	16647	16662	16676	16690	16704	16718	16732	**1440**
1450	16746	16760	16774	16789	16803	16817	16831	16845	16859	16873	**1450**
1460	16887	16901	16915	16930	16944	16958	16972	16986	17000	17014	**1460**
1470	17028	17042	17056	17071	17085	17099	17113	17127	17141	17155	**1470**
1480	17169	17183	17197	17211	17225	17240	17254	17268	17282	17296	**1480**
1490	17310	17324	17338	17352	17366	17380	17394	17408	17423	17437	**1490**
1500	17451	17465	17479	17493	17507	17521	17595	17549	17563	17577	**1500**
1510	17591	17605	17619	17633	17647	17661	17676	17690	17704	17718	**1510**
1520	17732	17746	17760	17774	17788	17802	17816	17830	17844	17858	**1520**
1530	17872	17886	17900	17914	17928	17942	17956	17970	17984	17998	**1530**
1540	18012	18026	18040	18054	18068	18082	18096	18118	18124	18138	**1540**
1550	18152	18166	18180	18194	18208	18222	18236	18250	18264	18278	**1550**
1560	18292	18306	18320	18334	18348	18362	18376	18390	18404	18417	**1560**
1570	18431	18445	18459	18473	18487	18501	18515	18529	18543	18557	**1570**
1580	18571	18585	18599	18613	18627	18640	18654	18668	18682	18696	**1580**
1590	18710	18724	18738	18752	18766	18779	18793	18807	18821	18835	**1590**
1600	18849	18863	18877	18891	18904	18918	18932	18946	18960	18974	**1600**
1610	18988	19002	19015	19029	19043	19057	19071	19085	19098	19112	**1610**

Type R Thermocouple Table

Platinum - 13% Rhodium/Platinum, Electromotive Force as a function of Temperature, E/μV
As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
1620	19126	19140	19154	19168	19181	19195	19209	19223	19237	19250	**1620**
1630	19264	19278	19292	19306	19319	19333	19347	19361	19375	19388	**1630**
1640	19402	19416	19430	19444	19457	19471	19485	19499	19512	19526	**1640**
1650	19540	19554	19567	19581	19595	19609	19622	19636	19650	19663	**1650**
1660	19677	19691	19705	19718	19732	19746	19759	19773	19787	19800	**1660**
1670	19814	19828	19841	19855	19869	19882	19896	19910	19923	19937	**1670**
1680	19951	19964	19978	19992	20005	20019	20032	20046	20060	20073	**1680**
1690	20087	20100	20114	20127	20141	20154	20168	20181	20195	20208	**1690**
1700	20222	20235	20249	20262	20275	20289	20302	20316	20329	20342	**1700**
1710	20356	20369	20382	20396	20409	20422	20436	20449	20462	20475	**1710**
1720	20488	20502	20515	20528	20541	20554	20567	20581	20594	20607	**1720**
1730	20620	20633	20646	20659	20672	20685	20698	20711	20724	20736	**1730**
1740	20749	20762	20775	20788	20801	20813	20826	20839	20852	20864	**1740**
1750	20877	20890	20902	20915	20928	20940	20953	20965	20978	20990	**1750**
1760	21003	21015	21027	21040	21052	21065	21077	21089	21101		**1760**

Type B Thermocouple Table

Platinum - 30% Rhodium/Platinum -6% Rhodium, EMF as a function of temperature, E/μV
As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
0	0	0	0	-1	-1	-1	-1	-1	-2	-2	**0**
10	-2	-2	-2	-2	-2	-2	-2	-2	-3	-3	**10**
20	-3	-3	-3	-3	-3	-2	-2	-2	-2	-2	**20**
30	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1	**30**
40	0	0	0	0	0	1	1	1	2	2	**40**
50	2	3	3	3	4	4	4	5	5	6	**50**
60	6	7	7	8	8	9	9	10	10	11	**60**
70	11	12	12	13	14	14	15	15	16	17	**70**
80	17	18	19	20	20	21	22	22	23	24	**80**
90	25	26	26	27	28	29	30	31	31	32	**90**
100	33	34	35	36	37	38	39	40	41	42	**100**
110	43	44	45	46	47	48	49	50	51	52	**110**
120	53	55	56	57	58	59	60	62	63	64	**120**
130	65	66	68	69	70	72	73	74	75	77	**130**
140	78	79	81	82	84	85	86	88	89	91	**140**
150	92	94	95	96	98	99	101	102	104	106	**150**
160	107	109	110	112	113	115	117	118	120	122	**160**
170	123	125	127	128	130	132	134	135	137	139	**170**
180	141	142	144	146	148	150	151	153	155	157	**180**
190	159	161	163	165	166	168	170	172	174	176	**190**
200	178	180	182	184	186	188	190	192	195	197	**200**
210	199	201	203	205	207	209	212	214	216	218	**210**
220	220	222	225	227	229	231	234	236	238	241	**220**
230	243	245	248	250	252	255	257	259	262	264	**230**
240	267	269	271	274	276	279	281	284	286	289	**240**
250	291	294	296	299	301	304	307	309	312	314	**250**
260	317	320	322	325	328	330	333	336	338	341	**260**
270	344	347	349	352	355	358	360	363	366	369	**270**
280	372	375	377	380	383	386	389	392	395	398	**280**
290	401	404	407	410	413	416	419	422	425	428	**290**
300	431	434	437	440	443	446	449	452	455	458	**300**
310	462	465	468	471	474	478	481	484	487	490	**310**
320	494	497	500	503	507	510	513	517	520	523	**320**
330	527	530	533	537	540	544	547	550	554	557	**330**
340	561	564	568	571	575	578	582	585	589	592	**340**
350	596	599	603	607	610	614	617	621	625	628	**350**
360	632	636	639	643	647	650	654	658	662	665	**360**
370	669	673	677	680	684	688	692	696	700	703	**370**
380	707	711	715	719	723	727	731	735	738	742	**380**
390	746	750	754	758	762	766	770	774	778	782	**390**
400	787	791	795	799	803	807	811	815	819	824	**400**
410	828	832	836	840	844	849	853	857	861	866	**410**
420	870	874	878	883	887	891	896	900	904	909	**420**
430	913	917	922	926	930	935	939	944	948	953	**430**
440	957	961	966	970	975	979	984	988	993	997	**440**
450	1002	1007	1011	1016	1020	1025	1030	1034	1039	1043	**450**
460	1048	1053	1057	1062	1067	1071	1076	1081	1086	1090	**460**
470	1095	1100	1105	1109	1114	1119	1124	1129	1133	1138	**470**
480	1143	1148	1153	1158	1163	1167	1172	1177	1182	1187	**480**
490	1192	1197	1202	1207	1212	1217	1222	1227	1232	1237	**490**
500	1242	1247	1252	1257	1262	1267	1272	1277	1282	1288	**500**
510	1293	1298	1303	1308	1313	1318	1324	1329	1334	1339	**510**

Type B Thermocouple Table

Platinum - 30% Rhodium/Platinum -6% Rhodium, EMF as a function of temperature, E/µV
As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
520	1344	1350	1355	1360	1365	1371	1376	1381	1387	1392	**520**
530	1397	1402	1408	1413	1418	1424	1429	1435	1440	1445	**530**
540	1451	1456	1462	1467	1472	1478	1483	1489	1494	1500	**540**
550	1505	1511	1516	1522	1527	1533	1539	1544	1550	1555	**550**
560	1561	1566	1572	1578	1583	1589	1595	1600	1606	1612	**560**
570	1617	1623	1629	1634	1640	1646	1652	1657	1663	1669	**570**
580	1675	1680	1686	1692	1698	1704	1709	1715	1721	1727	**580**
590	1733	1739	1745	1750	1756	1762	1768	1774	1780	1786	**590**
600	1792	1798	1804	1810	1816	1822	1828	1834	1840	1846	**600**
610	1852	1858	1864	1870	1876	1882	1888	1894	1901	1907	**610**
620	1913	1919	1925	1931	1937	1944	1950	1956	1962	1968	**620**
630	1975	1981	1987	1993	1999	2006	2012	2018	2025	2031	**630**
640	2037	2043	2050	2056	2062	2069	2075	2082	2088	2094	**640**
650	2101	2107	2113	2120	2126	2133	2139	2146	2152	2158	**650**
660	2165	2171	2178	2184	2191	2197	2204	2210	2217	2224	**660**
670	2230	2237	2243	2250	2256	2263	2270	2276	2283	2289	**670**
680	2296	2303	2309	2316	2323	2329	2336	2343	2350	2356	**680**
690	2363	2370	2376	2383	2390	2397	2403	2410	2417	2424	**690**
700	2431	2437	2444	2451	2458	2465	2472	2479	2485	2492	**700**
710	2499	2506	2513	2520	2527	2534	2541	2548	2555	2562	**710**
720	2569	2576	2583	2590	2597	2604	2611	2618	2625	2632	**720**
730	2639	2646	2653	2660	2667	2674	2681	2688	2696	2703	**730**
740	2710	2717	2724	2731	2738	2746	2753	2760	2767	2775	**740**
750	2782	2789	2796	2803	2811	2818	2825	2833	2840	2847	**750**
760	2854	2862	2869	2876	2884	2891	2898	2906	2913	2921	**760**
770	2928	2935	2943	2950	2958	2965	2973	2980	2987	2995	**770**
780	3002	3010	3017	3025	3032	3040	3047	3055	3062	3070	**780**
790	3078	3085	3093	3100	3108	3116	3123	3131	3138	3146	**790**
800	3154	3161	3169	3177	3184	3192	3200	3207	3215	3223	**800**
810	3230	3238	3246	3254	3261	3269	3277	3285	3292	3300	**810**
820	3308	3316	3324	3331	3339	3347	3355	3363	3371	3379	**820**
830	3386	3394	3402	3410	3418	3426	3434	3442	3450	3458	**830**
840	3466	3474	3482	3490	3498	3506	3514	3522	3530	3538	**840**
850	3546	3554	3562	3570	3578	3586	3594	3602	3610	3618	**850**
860	3626	3634	3643	3651	3659	3667	3675	3683	3692	3700	**860**
870	3708	3716	3724	3732	3741	3749	3757	3765	3774	3782	**870**
880	3790	3798	3807	3815	3823	3832	3840	3848	3857	3865	**880**
890	3873	3882	3890	3898	3907	3915	3923	3932	3940	3949	**890**
900	3957	3965	3974	3982	3991	3999	4008	4016	4024	4033	**900**
910	4041	4050	4058	4067	4075	4084	4093	4101	4110	4118	**910**
920	4127	4135	4144	4152	4161	4170	4178	4187	4195	4204	**920**
930	4213	4221	4230	4239	4247	4256	4265	4273	4282	4291	**930**
940	4299	4308	4317	4326	4334	4343	4352	4360	4369	4378	**940**
950	4387	4396	4404	4413	4422	4431	4440	4448	4457	4466	**950**
960	4475	4484	4493	4501	4510	4519	4528	4537	4546	4555	**960**
970	4564	4573	4582	4591	4599	4608	4617	4626	4635	4644	**970**
980	4653	4662	4671	4680	4689	4698	4707	4716	4725	4734	**980**
990	4743	4753	4762	4771	4780	4789	4798	4807	4816	4825	**990**
1000	4834	4843	4853	4862	4871	4880	4889	4898	4908	4917	**1000**
1010	4926	4935	4944	4954	4963	4972	4981	4990	5000	5009	**1010**
1020	5018	5027	5037	5046	5055	5065	5074	5083	5092	5102	**1020**
1030	5111	5120	5130	5139	5148	5158	5167	5176	5186	5195	**1030**
1040	5205	5214	5223	5233	5242	5252	5261	5270	5280	5289	**1040**
1050	5299	5308	5318	5327	5337	5346	5356	5365	5375	5384	**1050**
1060	5394	5403	5413	5422	5432	5441	5451	5460	5470	5480	**1060**
1070	5489	5499	5508	5518	5528	5537	5547	5556	5566	5576	**1070**

Type B Thermocouple Table

Platinum - 30% Rhodium/Platinum -6% Rhodium, EMF as a function of temperature, E/μV
As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
1080	5585	5595	5605	5614	5624	5634	5643	5653	5663	5672	**1080**
1090	5682	5692	5702	5711	5721	5731	5740	5750	5760	5770	**1090**
1100	5780	5789	5799	5809	5819	5828	5838	5848	5858	5868	**1100**
1110	5878	5887	5897	5907	5917	5927	5937	5947	5956	5966	**1110**
1120	5976	5986	5996	6006	6016	6026	6036	6046	6055	6065	**1120**
1130	6075	6085	6095	6105	6115	6125	6135	6145	6155	6165	**1130**
1140	6175	6185	6195	6205	6215	6225	6235	6245	6256	6266	**1140**
1150	6276	6286	6296	6306	6316	6326	6336	6346	6356	6367	**1150**
1160	6377	6387	6397	6407	6417	6427	6438	6448	6458	6468	**1160**
1170	6478	6488	6499	6509	6519	6529	6539	6550	6560	6570	**1170**
1180	6580	6591	6601	6611	6621	6632	6642	6652	6663	6673	**1180**
1190	6683	6693	6704	6714	6724	6735	6745	6755	6766	6776	**1190**
1200	6786	6797	6807	6818	6828	6838	6849	6859	6869	6880	**1200**
1210	6890	6901	6911	6922	6932	6942	6953	6963	6974	6984	**1210**
1220	6995	7005	7016	7029	7037	7047	7058	7068	7079	7089	**1220**
1230	7100	7110	7121	7131	7142	7152	7163	7173	7184	7194	**1230**
1240	7205	7216	7226	7237	7247	7258	7269	7279	7290	7300	**1240**
1250	7311	7322	7332	7343	7353	7364	7375	7385	7396	7407	**1250**
1260	7417	7428	7439	7449	7460	7471	7482	7492	7503	7514	**1260**
1270	7524	7535	7546	7557	7567	7578	7589	7600	7610	7621	**1270**
1280	7632	7643	7653	7664	7675	7686	7697	7707	7718	7729	**1280**
1290	7740	7751	7761	7772	7783	7794	7805	7816	7827	7837	**1290**
1300	7848	7859	7870	7881	7892	7903	7914	7924	7935	7946	**1300**
1310	7957	7968	7979	7990	8001	8012	2023	8034	8045	8056	**1310**
1320	8066	8077	8088	8099	8110	8121	8132	8143	8154	8165	**1320**
1330	8176	8187	8198	8209	8220	8231	8242	8253	8264	8275	**1330**
1340	8286	8298	8309	8320	8331	8392	8353	8364	8375	8386	**1340**
1350	8397	8408	8419	8430	8441	8454	8464	8475	8486	8497	**1350**
1360	8508	8519	8530	8542	8553	8564	8575	8586	8597	8608	**1360**
1370	8620	8631	8642	8653	8664	8675	8687	8698	8709	8720	**1370**
1380	8731	8743	8754	8765	8776	8787	8799	8810	8821	8832	**1380**
1390	8844	8855	8866	8877	8889	8900	8911	8922	8934	8945	**1390**
1400	8956	8967	8979	8990	9001	9013	9024	9035	9047	9058	**1400**
1410	9069	9080	9092	9103	9114	9126	9137	9148	9160	9171	**1410**
1420	9182	9194	9205	9216	9228	9239	9251	9262	9273	9285	**1420**
1430	9296	9307	9319	9330	9342	9353	9364	9376	9387	9398	**1430**
1440	9410	9421	9433	9444	9456	9467	9478	9490	9501	9513	**1440**
1450	9524	9536	9547	9558	9570	9581	9593	9604	9616	9627	**1450**
1460	9639	9650	9662	9673	9684	9696	9707	9719	9730	9742	**1460**
1470	9753	9765	9776	9788	9799	9811	9822	9834	9845	9857	**1470**
1480	9868	9880	9891	9903	9914	9926	9937	9949	9961	9972	**1480**
1490	9984	9995	10007	10018	10030	10041	10053	10064	10076	10088	**1490**
1500	10099	10111	10122	10134	10145	10157	10168	10180	10192	10203	**1500**
1510	10215	10226	10238	10249	10261	10273	10284	10296	10307	10319	**1510**
1520	10331	10342	10354	10365	10377	10389	10400	10412	10423	10435	**1520**
1530	10447	10458	10470	10482	10493	10505	10516	10528	10540	10551	**1530**
1540	10563	10575	10586	10598	10609	10621	10633	10644	10656	10668	**1540**
1550	10679	10691	10703	10714	10726	10738	10749	10761	10773	10784	**1550**
1560	10796	10808	10819	10831	10843	10854	10866	10877	10889	10901	**1560**
1570	10913	10924	10936	10948	10959	10971	10983	10994	11006	11018	**1570**
1580	11029	11041	11053	11064	11076	11088	11099	11111	11123	11134	**1580**
1590	11146	11158	11169	11181	11193	11205	11216	11228	11240	11251	**1590**
1600	11263	11275	11286	11298	11310	11321	11333	11345	11357	11368	**1600**
1610	11380	11392	11403	11415	11427	11438	11450	11462	11474	11485	**1610**
1620	11497	11509	11520	11532	11544	11555	11567	11579	11591	11602	**1620**
1630	11614	11626	11637	11649	11661	11673	11684	11696	11708	11719	**1630**

Type B Thermocouple Table

Platinum - 30% Rhodium/Platinum -6% Rhodium, EMF as a function of temperature, E/μV

As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
1640	11731	11743	11754	11766	11778	11790	11801	11813	11825	11836	**1640**
1650	11848	11860	11871	11883	11895	11907	11918	11930	11942	11953	**1650**
1660	11965	11977	11988	12000	12012	12024	12035	12047	12059	12070	**1660**
1670	12082	12094	12105	12117	12129	12141	12152	12164	12176	12187	**1670**
1680	12199	12211	12222	12234	12246	12257	12269	12281	12292	12304	**1680**
1690	12316	12327	12339	12351	12363	12374	12386	12398	12409	12421	**1690**
1700	12433	12444	12456	12468	12479	12491	12503	12514	12526	12538	**1700**
1710	12549	12561	12572	12584	12596	12607	12619	12631	12642	12654	**1710**
1720	12666	12677	12689	12701	12712	12724	12736	12747	12759	12770	**1720**
1730	12782	12794	12805	12817	12829	12840	12852	12863	12875	12887	**1730**
1740	12898	12910	12921	12933	12945	12956	12968	12980	12991	13003	**1740**
1750	13014	13026	13037	13049	13061	13072	13084	13095	13107	13119	**1750**
1760	13130	13142	13153	13165	13176	13188	13200	13211	13223	13234	**1760**
1770	13246	13257	13269	13280	13292	13304	13315	13327	13338	13350	**1770**
1780	13361	13373	13384	13396	13407	13419	13430	13442	13453	13465	**1780**
1790	13476	13488	13499	13511	13522	13594	13545	13557	13568	13580	**1790**
1800	13591	13603	13614	13626	13637	13649	13660	13672	13683	13694	**1800**
1810	13706	13717	13729	13740	13752	13763	13775	13786	13797	13809	**1810**
18	13820										**1820**

Type K Thermocouple Table

Nickel-Chromium/Nickel-Aluminium, Electromotive Force as a function of temperature, E/µV

As per Standard ASTM E230

t90/°C	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	t90/°C
-270	-6458										**-270**
-260	-6441	-6444	-6446	-6448	-6450	-5452	-6453	-6455	-6456	-6457	**-260**
-250	-6404	-6408	-6413	-6417	-6421	-5425	-6429	-6432	-6435	-6438	**-250**
-240	-6344	-6351	-6358	-6364	-6370	-6377	-6382	-6388	-6393	-6399	**-240**
-230	-6262	-6271	-6280	-6289	-6297	-6306	-6314	-6322	-6329	-6337	**-230**
-220	-6158	-6170	-6181	-6192	-6202	-6213	-6223	-6233	-6243	-6252	**-220**
-210	-6035	-6048	-6061	-6074	-6087	-6099	-6111	-6123	-6135	-6147	**-210**
-200	-5891	-5907	-5922	-5936	-5951	-5965	-5980	-5994	-6007	-6021	**-200**
-190	-5730	-5747	-5763	-5780	-5797	-5813	-5829	-5845	-5861	-5876	**-190**
-180	-5550	-5569	-5588	-5606	-5624	-5642	-5660	-5678	-5695	-5713	**-180**
-170	-5354	-5374	-5395	-5415	-5435	-5454	-5474	-5493	-5512	-5531	**-170**
-160	-5141	-5163	-5185	-5207	-5228	-5250	-5271	-5292	-5313	-5333	**-160**
-150	-4913	-4936	-4960	-4983	-5006	-5029	-5052	-5074	-5097	-5119	**-150**
-140	-4669	-4694	-4719	-4744	-4768	-4793	-4817	-4841	-4865	-4889	**-140**
-130	-4411	-4437	4463	-4490	-4516	-4542	-4567	-4593	-4618	-4644	**-130**
-120	-4138	-4166	-4194	-4221	-4249	-4276	-4303	-4330	-4357	-4384	**-120**
-110	-3852	-3882	-3911	-3939	-3968	-3997	-4025	-4054	-4082	-4110	**-110**
-100	-3554	-3584	-3614	-3645	-3675	-3705	-3734	-3764	-3794	-3823	**-100**
-90	-3243	-3274	-3306	-3337	-3368	-3400	-3431	-3462	-3492	-3523	**-90**
-80	-2920	-2953	-2986	-3018	-3050	-3083	-3115	-3147	-3179	-3211	**-80**
-70	-2587	-2620	-2654	-2688	-2721	-2755	-2788	-2821	-2854	-2887	**-70**
-60	-2243	-2278	-2312	-2347	-2382	-2416	-2450	-2485	-2519	-2553	**-60**
-50	-1889	-1925	-1961	-1996	-2032	-2067	-2103	-2138	-2173	-2208	**-50**
-40	-1527	-1564	-1600	-1637	-1673	-1709	-1745	-1782	-1818	-1854	**-40**
-30	-1156	-1194	-1231	-1268	-1305	-1343	-1380	-1417	-1453	-1490	**-30**
-20	-778	-816	-854	-892	-930	-968	-1006	-1043	-1081	-1119	**-20**
-10	-392	-431	-470	-508	-547	-586	-624	-663	-701	-739	**-10**
0	0	-39	-79	-118	-157	-197	-236	-275	-314	-353	**0**
t90/°C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**t90/°C**
0	0	39	79	119	158	198	238	277	317	357	**0**
10	397	437	477	517	557	597	637	677	718	758	**10**
20	798	838	879	919	960	1000	1041	1081	1122	1163	**20**
30	1203	1244	1285	1326	1366	1407	1448	1489	1530	1571	**30**
40	1612	1653	1694	1735	1776	1817	1858	1899	1941	1982	**40**
50	2023	2064	2106	2147	2188	2230	2271	2312	2354	2397	**50**
60	2436	2478	2519	2561	2602	2644	2685	2727	2768	2810	**60**
70	2851	2893	2934	2976	3017	3059	3100	3142	3184	3225	**70**
80	3267	3308	3350	3391	3433	3474	3516	3557	3599	3640	**80**
90	3682	3723	3765	3806	3848	3889	3931	3972	4013	4055	**90**
100	4096	4138	4179	4220	4262	4303	4344	4385	4427	4468	**100**
110	4509	4550	4561	4633	4674	4715	4756	4797	4838	4879	**110**
120	4920	4961	5002	5043	5084	5124	5165	5206	5247	5288	**120**
130	5328	5369	5410	5450	5491	5532	5572	5613	5653	5694	**130**
140	5735	5775	5815	5856	5896	5937	5977	6017	6058	6098	**140**
150	6138	6179	6219	6259	6299	6339	6380	6420	6460	6500	**150**
160	6540	6580	6620	6660	6701	6741	6781	6821	6861	6901	**160**
170	6941	6981	6620	7060	7100	7140	7180	7220	7260	7300	**170**
180	7340	7380	7021	7460	7500	7540	7579	7619	7659	7699	**180**
190	7739	7779	7420	7859	7899	7939	7979	8019	8059	8099	**190**
200	8138	8178	7819	8258	8298	8338	8378	8418	8458	8499	**200**
210	8539	8579	8218	8659	8699	8739	8779	8819	8860	8900	**210**
220	8940	8980	8619	9061	9101	9141	9181	9222	9262	9302	**220**
230	9343	9383	9020	9464	9504	9545	9585	9626	9666	9707	**230**

Type K Thermocouple Table

Nickel-Chromium/Nickel-Aluminium, Electromotive Force as a function of temperature, E/μV

As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
240	9747	9788	9828	9869	9909	9950	9991	10031	10072	10113	**240**
250	10153	10194	10235	10276	10316	10357	10398	10439	10480	10520	**250**
260	10561	10602	10643	10684	10725	10766	10807	10848	10889	10930	**260**
270	10971	11012	11053	11094	11135	11176	11217	11259	11300	11341	**270**
280	11382	11423	11465	11506	11547	11588	11630	11671	11712	11753	**280**
290	11795	11836	11877	11919	11960	12001	12043	12084	12126	12167	**290**
300	12209	12250	12291	12333	12374	12416	12457	12499	12540	12582	**300**
310	12624	12665	12707	12748	12790	12831	12873	12915	12956	12998	**310**
320	13040	13081	13123	13165	13206	13248	13290	13331	13373	13415	**320**
330	13457	13498	13540	13582	13624	13665	13707	13749	13791	13833	**330**
340	13874	13916	13958	14000	14042	14084	14126	14167	14209	14251	**340**
350	14293	14335	14377	14419	14461	14503	14545	14587	14629	14671	**350**
360	14713	14755	14797	14839	14881	14923	14965	15007	15049	15091	**360**
370	15133	15175	15217	15259	15301	15343	15385	15427	15469	15511	**370**
380	15554	15596	15638	15680	15722	15764	15806	15849	15891	15933	**380**
390	15975	16017	16059	16102	16144	16186	16228	16270	16313	16355	**390**
400	16397	16439	16482	16524	16566	16608	16651	16693	16735	16778	**400**
410	16820	16862	16904	16947	16989	17031	17074	17116	17158	17201	**410**
420	17243	17285	17328	17370	17413	17455	17497	17540	17582	17624	**420**
430	17667	17709	17752	17794	17837	17879	17921	17964	18006	18049	**430**
440	18091	18134	18176	18218	18261	18303	18346	18388	18431	18473	**440**
450	18516	18558	18601	18643	18686	18728	18771	18813	18856	18898	**450**
460	18941	18983	19026	19068	19111	19154	19196	19239	19281	19324	**460**
470	19366	19409	19451	19494	19537	19579	19622	19664	19707	19750	**470**
480	19792	19835	19877	19920	19962	20005	20048	20090	20133	20175	**480**
490	20218	20261	20303	20346	20389	20431	20474	20516	20559	20605	**490**
500	20644	20687	20730	20772	20815	20857	20900	20943	20985	21028	**500**
510	21071	21113	21156	21199	21241	21284	21326	21369	21412	21454	**510**
520	21497	21540	21582	21625	21668	21710	21753	21796	21838	21881	**520**
530	21924	21966	22009	22052	22094	22137	22179	22222	22265	22307	**530**
540	22350	22393	22435	22478	22521	22563	22606	22649	22691	22734	**540**
550	22776	22819	22862	22904	22947	22990	23032	23075	23117	23160	**550**
560	23203	23245	23288	23331	23373	23416	23458	23501	23544	23586	**560**
570	23629	23671	23714	23757	23799	23842	23884	23927	23970	24012	**570**
580	24055	24097	24140	24182	24225	24267	24310	24353	24395	24438	**580**
590	24480	24523	24565	24608	24650	24693	24735	24778	24820	24863	**590**
600	24905	24948	24990	25033	25075	25118	25160	25203	25245	25288	**600**
610	25330	25373	25415	25458	25500	25543	25585	25627	25670	25712	**610**
620	25755	25797	25840	25882	25924	25967	26009	26052	26094	26136	**620**
630	26179	26221	26263	26306	26348	26390	26433	26475	26517	26560	**630**
640	26602	26644	26687	26729	26771	26814	26856	26898	26940	26983	**640**
650	27025	27067	27109	27152	27194	27236	27278	27320	27363	27405	**650**
660	27447	27489	27531	27574	27616	27658	27700	27742	27784	27826	**660**
670	27869	27911	27953	27995	28037	28079	28121	28163	28205	28247	**670**
680	28289	28332	28374	28416	28458	28500	28542	28584	28626	28668	**680**
690	28710	28752	28794	28835	28877	28919	28961	29003	29045	29087	**690**
700	29129	29171	29213	29255	29297	29338	29380	29422	29464	29506	**700**
710	29548	29589	29631	29673	29715	29757	29798	29840	29882	29924	**710**
720	29965	30007	30049	30090	30132	30174	30216	30257	30299	30341	**720**
730	30382	30424	30466	30507	30549	30590	30632	30674	30715	30757	**730**
740	30798	30840	30881	30923	30964	31006	31047	31089	31130	31172	**740**
750	31213	31255	31296	31338	31379	31421	31462	31504	31545	31586	**750**
760	31628	31669	31710	31752	31793	31834	31876	31917	31958	32000	**760**
770	32041	32082	32124	32165	32206	32247	32289	32330	32371	32412	**770**
780	32453	32495	32536	32577	32618	32659	32700	32742	32783	32824	**780**
790	32865	32906	32947	32988	33029	33070	33111	33152	33193	33234	**790**

Type K Thermocouple Table

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
800	33275	33316	33357	33398	33439	33480	33521	33562	33603	33644	**800**
810	33685	33726	33767	33808	33848	33889	33930	33971	34012	34053	**810**
820	34093	34134	34175	34216	34257	34297	34338	34379	34420	34460	**820**
830	34501	34542	34582	34623	34664	34704	34745	34786	34826	34867	**830**
840	34908	34948	34989	35029	35070	34110	35151	35192	35232	35273	**840**
850	35313	35354	35394	35435	35475	35516	35556	35596	35637	35677	**850**
860	35718	35758	35798	35839	35879	35920	35960	36000	36041	36081	**860**
870	36121	36162	36202	36242	36282	36323	36363	36403	36443	36484	**870**
880	36524	36564	36604	36644	36685	36725	36765	36805	36845	36885	**880**
890	36925	36965	37006	37046	37086	37125	37166	37206	37246	37286	**890**
900	37326	37366	37406	37446	37486	37526	37566	37606	37646	37686	**900**
910	37725	37765	37805	37845	37885	37925	37965	38005	38044	38084	**910**
920	38124	38164	38204	38243	38283	38323	38363	38402	38442	38482	**920**
930	38522	38561	38601	38641	38680	38720	38760	38799	38839	38878	**930**
940	38918	38958	38997	39037	39076	39116	39155	39195	39235	39274	**940**
950	39314	39353	39393	39432	39471	39511	39550	39590	39629	39669	**950**
960	39708	39747	39787	39826	39866	39905	39944	39984	40023	40062	**960**
970	40101	40141	40180	40219	40259	40298	40337	40376	40415	40455	**970**
980	40494	40533	40572	40611	40651	40690	40729	40768	40807	40846	**980**
990	40885	40924	40963	41002	41042	41081	41120	41156	41198	41237	**990**
1000	41276	41315	41354	41393	41431	41470	41509	41548	41587	41626	**1000**
1010	41665	41704	41743	41781	41820	41859	41898	41937	41976	42014	**1010**
1020	42053	42092	42131	42169	42208	42247	42286	42324	42363	42402	**1020**
1030	42440	42479	42518	42556	42595	42633	42672	42711	42749	42788	**1030**
1040	42826	42865	42903	42942	42980	43019	43057	43096	43134	43173	**1040**
1050	43211	43250	43288	43327	43365	43403	43442	43480	43518	43557	**1050**
1060	43595	43633	43672	43710	43748	43787	43825	43863	43901	43940	**1060**
1070	43978	44016	44054	44092	44130	44169	44207	44245	44283	44321	**1070**
1080	44359	44397	44435	44473	44512	44550	44588	44626	44664	44702	**1080**
1090	44740	44778	44816	44853	44891	44929	44967	45005	45043	45081	**1090**
1100	45119	45157	45194	45232	45270	45308	45346	45383	45421	45459	**1100**
1110	45497	45534	45572	45610	45647	45685	45723	45760	45798	45836	**1110**
1120	45873	45911	45948	45986	46024	46061	46099	46136	46174	46211	**1120**
1130	46249	46286	46324	46361	46398	46436	46473	46511	46548	46585	**1130**
1140	46623	46660	46697	46735	46772	46809	46847	46884	46921	46958	**1140**
1150	46995	47033	47070	47107	47144	47181	47218	47256	47293	47330	**1150**
1160	47367	47404	47441	47478	47515	47552	47589	47626	41663	47700	**1160**
1170	47737	47774	47811	47848	47884	47921	47958	47995	48032	48069	**1170**
1180	48105	48142	48179	48216	48252	48289	48326	48363	48399	48436	**1180**
1190	48473	48509	48546	48582	48619	48656	48692	48729	48765	48802	**1190**
1200	48838	48875	48911	48948	48984	49021	49057	49093	49130	49166	**1200**
1210	49202	49239	49275	49311	49348	49384	49420	49456	49493	49529	**1210**
1220	49565	49601	49637	49674	49710	49746	49782	49818	49854	49890	**1220**
1230	49926	49962	49998	50034	50070	50106	50142	50178	50214	50250	**1230**
1240	50286	50322	50358	50393	50429	50465	50501	50537	50572	50608	**1240**
1250	50644	50680	50715	50751	50787	50822	50858	50894	50929	50965	**1250**
1260	51000	51036	51071	51107	51142	51178	51213	51249	51284	51320	**1260**
1270	51355	51391	51426	51461	51497	51532	51567	51603	51638	51673	**1270**
1280	51708	51744	51779	51814	51849	51885	51920	51955	51990	52025	**1280**
1290	52060	52095	52130	52165	52200	52235	52270	52305	52340	52375	**1290**
1300	52410	52445	52480	52516	52550	52585	52620	52654	52689	52724	**1300**
1310	52759	52794	52828	52865	52898	52932	52967	53002	53037	53071	**1310**
1320	53106	53140	53175	53210	53244	53279	53313	53348	53382	53417	**1320**
1330	53451	53486	53520	53555	53589	53623	53658	53692	53727	53761	**1330**
1340	53795	53830	53864	53898	53932	53967	54001	54035	54069	54104	**1340**
1350	54138	54172	54206	54240	54274	54308	54343	54377	54411	54445	**1350**
1360	54479	54513	54547	54581	54615	54649	54683	54717	54751	54785	**1360**
1370	54819	54852	54886								**1370**

Type N Thermocouple Table

Nickel-Chromium-Silicon/Nickel-Silicon, Electromotive Force as a function of temperature, E/µV

As per Standard ASTM E230

t90/°C	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	t90/°C
-270	-4345										-270
-260	-4336	-4337	-4339	-4340	-4341	-4342	-4343	-4344	-4345	-4345	-260
-250	-4313	-4316	-4319	-4321	-4324	-4326	-4328	-4330	-4334	-4334	-250
-240	-4277	-4281	-4285	-4289	-4293	-4297	-4300	-4304	-4310	-4310	-240
-230	-4226	-4232	-4238	-4243	-4248	-4254	-4258	-4263	-4273	-4273	-230
-220	-4162	-4169	-4176	-4183	-4189	-4196	-4202	-4209	-4221	-4221	-220
-210	-4083	-4091	-4100	-4108	-4116	-4124	-4132	-4140	-4154	-4154	-210
-200	-3990	-4000	-4010	-4020	-4029	-4038	-4048	-4057	-4074	-4074	-200
-190	-3884	-3896	-3907	-3918	-3928	-3939	-3950	-3960	-3980	-3980	-190
-180	-3766	-3778	-3790	-3803	-3815	-3827	-3838	-3850	-3873	-3873	-180
-170	-3634	-3648	-3662	-3675	-3688	-3702	-3715	-3728	-3753	-3753	-170
-160	-3491	-3506	-3521	-3535	-3550	-3564	-3578	-3593	-3621	-3621	-160
-150	-3336	-3352	-3368	-3384	-3400	-3415	-3431	-3446	-3476	-3476	-150
-140	-3171	-3188	-3205	-3221	-3238	-3255	-3271	-3288	-3320	-3320	-140
-130	-2994	-3012	-3030	-3048	-3066	-3084	-3101	-3119	-3153	-3153	-130
-120	-2808	-2827	-2846	-2865	-2883	-2902	-2921	-2939	-2976	-2976	-120
-110	-2612	-2632	-2652	-2672	-2691	-2711	-2730	-2750	-2789	-2789	-110
-100	-2407	-2428	-2448	-2469	-2490	-2510	-2531	-2551	-2592	-2592	-100
-90	-2193	-2215	-2237	-2258	-2280	-2301	-2322	-2344	-2386	-2386	-90
-80	-1972	-1995	-2017	-2039	-2062	-2084	-2106	-2128	-2172	-2172	-80
-70	-1744	-1767	-1790	-1813	-1836	-1859	-1882	-1905	-1950	-1950	-70
-60	-1509	-1533	-1557	-1580	-1604	-1627	-1651	-1674	-1721	-1721	-60
-50	-1269	-1293	-1317	-1341	-1366	-1390	-1414	-1438	-1485	-1485	-50
-40	-1023	-1048	-1072	-1097	-1122	-1146	-1171	-1195	-1244	-1244	-40
-30	-772	-798	-823	-848	-873	-898	-923	-948	-999	-998	-30
-20	-518	-544	-569	-595	-620	-646	-671	-696	-747	-747	-20
-10	-260	-286	-312	-338	-364	-390	-415	-441	-495	-492	-10
0	0	-26	-52	-78	-104	-131	-157	-183	-234	-232	0

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
0	0	26	52	78	104	130	156	182	208	235	0
10	261	287	313	340	366	393	419	446	472	499	10
20	525	552	578	605	632	659	685	712	739	766	20
30	793	820	847	874	901	928	955	983	1010	1037	30
40	1065	1092	1119	1174	1174	1202	1229	1257	1284	1312	40
50	1340	1368	1395	1423	1451	1479	1507	1535	1563	1591	50
60	1619	1647	1675	1703	1732	1760	1788	1817	1845	1873	60
70	1902	1930	1959	1988	2016	2045	2074	2102	2131	2160	70
80	2189	2218	2247	2276	2305	2334	2363	2392	2421	2450	80
90	2480	2509	2538	2568	2597	2626	2656	2685	2715	2744	90
100	2774	2804	2833	2863	2893	2923	2953	2983	3012	3042	100
110	3074	3102	3133	3163	3193	3223	3253	3283	3314	3344	110
120	3374	3405	3435	3466	3496	3527	3557	3588	3619	3649	120
130	3680	3711	3742	3772	3803	3834	3865	3896	3927	3958	130
140	3989	4020	4051	4083	4114	4145	4176	4208	4239	4270	140
150	4302	4333	4365	4396	4428	4459	4491	4523	4554	4586	150
160	4618	4650	4681	4713	4745	4777	4809	4841	4873	4905	160
170	4937	4969	5001	5033	5066	5098	5130	5162	5195	5227	170
180	5259	5292	5324	5357	5389	5422	5454	5487	5520	5552	180
190	5585	5618	5650	5683	5716	5749	5782	5815	5847	5880	190
200	5913	5946	5979	6013	6046	6079	6112	6145	6178	6211	200

Type N Thermocouple Table

Nickel-Chromium-Silicon/Nickel-Silicon, Electromotive Force as a function of temperature, E/µV

As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
210	6245	6278	6311	6345	6378	6477	6445	6478	6512	6545	**210**
220	6579	6612	6646	6680	6713	6747	6781	6814	6848	6882	**220**
230	6916	6949	6983	7017	7051	7085	7119	7153	7187	7221	**230**
240	7255	7289	7323	7357	7392	7426	7460	7494	7528	7563	**240**
250	7597	7631	7666	7700	7734	7769	7803	7838	7872	7907	**250**
260	7941	7976	8010	8045	8080	8114	8149	8184	8212	8253	**260**
270	8288	8323	8358	8392	8427	8462	8497	8532	8567	8602	**270**
280	8637	8672	8707	8742	8777	8812	8847	8882	8918	8953	**280**
290	8988	9023	9508	9094	9129	9164	9200	9235	9270	9306	**290**
300	9341	9377	9412	9448	9483	9519	9554	9590	9625	9661	**300**
310	9696	9732	9768	9803	9839	9875	9910	9946	9982	10018	**310**
320	10054	10089	10125	10161	10197	10233	10269	10305	10341	10377	**320**
330	10413	10449	10485	10521	10557	10593	10629	10665	10701	10737	**330**
340	10774	10810	10846	10882	10918	10955	10991	11027	11064	11100	**340**
350	11136	11173	11209	11245	11282	11318	11355	11391	11428	11464	**350**
360	11501	11537	11574	11610	11647	11683	11720	11757	11793	11830	**360**
370	11867	11903	11940	11977	12013	12050	12087	12124	12160	12197	**370**
380	12234	12271	12308	12345	12382	12418	12455	12492	12529	12566	**380**
390	12603	12640	12677	12714	12751	12788	12825	12862	12899	12937	**390**
400	12974	13011	13048	13085	13122	13159	13197	13234	13271	13308	**400**
410	13346	13383	13420	13457	13495	13532	13569	13607	13644	13682	**410**
420	13719	13756	13794	13831	13869	13906	13944	13981	14019	14056	**420**
430	14094	14131	14169	14206	14244	14281	14319	14356	14394	14432	**430**
440	14469	14507	14545	14582	14620	14658	14695	14733	14771	14809	**440**
450	14846	14884	14922	14960	14998	15035	15073	15111	15149	15187	**450**
460	15225	15262	15300	15338	15376	15414	15452	15490	15528	15566	**460**
470	15604	15642	15380	15718	15756	15794	15832	15870	15908	15946	**470**
480	15984	16022	16060	16099	16137	16175	16213	16251	16289	16327	**480**
490	16366	16404	16442	16480	16518	16557	16595	16633	16671	16710	**490**
500	16748	16786	16824	16863	16901	16939	16978	17016	17054	17093	**500**
510	17131	17169	17208	17246	17285	17323	17361	17400	17438	17477	**510**
520	17515	17554	17592	17630	17669	17707	17746	17784	17823	17861	**520**
530	17900	17938	17977	18016	18054	18093	18131	18170	18208	18247	**530**
540	18286	18324	18363	18401	18440	18479	18517	18556	18595	18633	**540**
550	18672	18711	18749	18788	18827	18865	18904	18943	18982	19020	**550**
560	19059	19098	19136	19175	19214	19253	19202	19330	19369	19408	**560**
570	19447	19485	19524	19563	19602	19641	19680	19718	19575	19796	**570**
580	19835	19874	19913	19952	19990	20029	20068	20107	20146	20185	**580**
590	20224	20263	20302	20341	20379	20418	20457	20496	20535	20574	**590**
600	20613	20652	20691	20730	20769	20808	20847	20886	20925	20964	**600**
610	21003	21042	21081	21120	21159	21198	21237	21276	21315	21354	**610**
620	21393	21432	21471	21510	21549	21588	21628	21667	21706	21745	**620**
630	21784	21823	21862	21901	21940	21979	22018	22058	22097	22136	**630**
640	22175	22214	22253	22292	22331	22370	22410	22449	22488	22527	**640**
650	22566	22605	22644	22684	22723	22762	22801	22840	22879	22919	**650**
660	22958	22997	23036	23075	23115	23154	23193	23232	23271	23311	**660**
670	23350	23389	23428	29467	23507	13546	23585	23624	23663	23703	**670**
680	23742	23781	23820	23860	23899	23938	23977	24016	24056	24095	**680**
690	24134	24173	24213	24252	24291	24330	24370	24409	24448	24487	**690**
700	24527	24566	24605	24644	24684	24723	24762	24801	24841	24880	**700**
710	24919	24959	24998	25037	25076	25116	25155	25194	25233	25273	**710**
720	25312	25351	25391	25430	25469	25508	25548	25587	25626	25666	**720**
730	25705	25744	25783	25823	25862	25901	25941	25980	26019	26058	**730**
740	26098	26137	26176	26216	26255	26294	26333	26373	26412	26451	**740**
750	26491	26530	26569	26608	26648	26687	26726	26766	26805	26844	**750**
760	26883	26923	26962	27001	27041	27080	27119	27158	27198	27237	**760**
770	27276	27316	27355	27394	27433	27473	27512	27551	27591	27630	**770**

Type N Thermocouple Table

Nickel-Chromium-Silicon/Nickel-Silicon, Electromotive Force as a function of temperature, E/μV

As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
780	27669	27708	27748	27787	27826	27866	27905	27944	27983	28023	**780**
790	28062	28101	28140	28180	28219	28258	28297	28337	28376	28415	**790**
800	28455	28494	28533	28572	28612	28651	28690	28729	28769	28808	**800**
810	28847	28886	28926	28965	29004	29043	29083	29122	29161	29200	**810**
820	29239	29279	29318	29357	29396	29436	29475	29514	29553	29592	**820**
830	29632	29671	29710	29749	29789	29828	29867	29906	26645	29985	**830**
840	30024	30063	30102	30141	30181	30220	30259	30298	30337	30376	**840**
850	30416	30455	30494	30533	30572	30611	30651	30690	30729	30768	**850**
860	30807	30846	30866	30925	30964	31003	31042	31081	31120	31160	**860**
870	31199	31238	31277	31316	31355	31394	31433	31473	31512	31551	**870**
880	37590	31629	31668	31707	31746	31785	31824	31863	31903	31942	**880**
890	31981	32020	32059	32098	32137	32176	32215	32254	32293	32332	**890**
900	32371	32410	32449	33488	32527	32566	32605	32644	32683	32722	**900**
910	32761	32800	32839	32878	32917	32956	32995	33034	33073	33112	**910**
920	33151	33190	33229	33268	33307	33346	33385	33424	33463	33502	**920**
930	33541	33580	33619	33658	33697	33736	33774	33813	33852	33891	**930**
940	33930	33969	34008	34047	34086	34124	34163	34202	34241	34280	**940**
950	34319	34358	34396	34435	34474	34513	34552	34591	34629	34668	**950**
960	34707	34746	34785	34823	34862	34901	34940	34979	35017	35056	**960**
970	35095	35134	35172	35211	35250	35289	35327	35366	35405	35444	**970**
980	35482	35521	35560	35598	35637	35676	35714	35753	35792	35831	**980**
990	35869	35908	35946	35985	36024	36062	36101	36140	36178	36217	**990**
1000	36256	36294	36333	36371	36410	36449	36487	36526	36564	36603	**1000**
1010	36641	36680	36718	36757	36796	36834	36873	36911	36950	36988	**1010**
1020	37027	37065	37104	37142	37181	37219	37258	37296	37334	37373	**1020**
1030	37411	37450	37488	37525	37565	37603	37642	37680	37719	37757	**1030**
1040	37795	37834	37872	37911	37949	37987	38026	38064	38102	38141	**1040**
1050	38179	38217	38256	38294	38332	38370	38409	38447	38485	38524	**1050**
1060	38562	38600	38638	38677	38715	38753	38791	38829	38868	38906	**1060**
1070	38944	38982	39020	39059	39097	39135	39173	39211	39249	39287	**1070**
1080	39326	39364	39402	39440	39478	39516	39554	39592	39630	39668	**1080**
1090	39706	39744	39783	39821	39859	39897	39935	39973	40011	40049	**1090**
1100	40087	40125	40163	40201	40238	40276	40314	40352	40390	40428	**1100**
1110	40466	40504	40542	40580	40618	40655	40693	40731	40769	40807	**1110**
1120	40845	40883	40920	40958	40996	41034	41072	41109	41147	41185	**1120**
1130	41223	41260	41298	41336	41374	41411	41449	41487	41525	41562	**1130**
1140	41600	41638	41675	41713	41751	41788	41826	41864	41901	41939	**1140**
1150	41976	42014	42052	42089	42127	42164	42202	42239	42277	42314	**1150**
1160	42352	42390	42427	42465	42502	42540	42577	42614	42652	42689	**1160**
1170	42727	42764	42802	42839	42877	42914	42951	42989	43026	43064	**1170**
1180	43101	43138	43176	43213	43250	43288	43325	43362	43399	43437	**1180**
1190	43474	43511	43549	43586	43623	43660	43698	43735	43772	43809	**1190**
1200	43846	43884	43921	43958	43995	44032	44069	44106	44144	44181	**1200**
1210	44218	44255	44292	44329	44366	44403	44440	44477	44514	44551	**1210**
1220	44588	44625	44662	44699	44736	44773	44810	44847	44884	44921	**1220**
1230	44958	44995	45032	45069	45105	45142	45179	45216	45253	45290	**1230**
1240	45326	45363	45400	45437	45474	45510	45547	45584	45621	45657	**1240**
1250	45694	45731	45767	45804	45841	45877	45914	45351	45987	46024	**1250**
1260	46060	46097	46133	46170	46207	46243	46280	46316	46353	46389	**1260**
1270	46425	46462	46498	46535	46571	46608	46644	46680	46717	46753	**1270**
1280	46789	46286	46862	46898	46935	46971	47007	47043	47079	47116	**1280**
1290	47152	47188	47224	47260	47296	47333	47369	47405	47441	47477	**1290**
1300	47513										**1300**

Type J Thermocouple Table

Iron/Copper-Nickel, Electromotive Force as a function of temperature, E/µV

As per Standard ASTM E230

t90/°C	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	t90/°C
-210	-8095										**-210**
-200	-7890	-7912	-7734	-7955	-7976	-7996	-8017	-8037	-8057	-8076	**-200**
-190	-7659	-7683	-7707	-7731	-7755	-7778	-1801	-7824	-7846	-7868	**-190**
-180	-7403	-7429	-7456	-7482	-7508	-7534	-7559	-7585	-7610	-7634	**-180**
-170	-7123	-7152	-7181	-7209	-7237	-7265	-7293	-7321	-7348	-7376	**-170**
-160	-6831	-6853	-6883	-6914	-6944	-6975	-7005	-7035	-7064	-7094	**-160**
-150	-6500	-6533	-6566	-6598	-6631	-6663	-6695	-6727	-6759	-6790	**-150**
-140	-6159	-6194	-6229	-6263	-6298	-6332	-6366	-6400	-6433	-6467	**-140**
-130	-5801	-5838	-5824	-5910	-5946	-5982	-6018	-6054	-6089	-6124	**-130**
-120	-5426	-5465	-5503	-5541	-5578	-5616	-5653	-5690	-5727	-5764	**-120**
-110	-5037	-5076	-5116	-5155	-5194	-5233	-5272	-5311	-5350	-5388	**-110**
-100	-4633	-4674	-4714	-4755	-4796	-4836	-4877	-4917	-4957	-4997	**-100**
-90	-4215	-4257	-4300	-4342	-4384	-4425	-4467	-4509	-4550	-4591	**-90**
-80	-3786	-3829	-3872	-3916	-3959	-4002	-4045	-4088	-4130	-4173	**-80**
-70	-3344	-3389	-3434	-3478	-3522	-3566	-3610	-3654	-3698	-3742	**-70**
-60	-2893	-2938	-2984	-3029	-3075	-3120	-3165	-3210	-3255	-3300	**-60**
-50	-2431	-2478	-2524	-2571	-2617	-2663	-2709	-2755	-2801	-2847	**-50**
-40	-1961	-2008	-2055	-2103	-2150	-2197	-2244	-2291	-2338	-2385	**-40**
-30	-1482	-1530	-1578	-1626	-1674	-1722	-1770	-1818	-1865	-1913	**-30**
-20	-995	-1044	-1093	-1142	-1190	-1239	-1288	-1336	-1385	-1433	**-20**
-10	-501	-550	-600	-650	-699	-749	-798	-847	-896	-946	**-10**
0	0	-50	-101	-151	-201	-251	-301	-351	-401	-451	**0**

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
0	0	50	101	151	202	253	303	354	405	456	**0**
10	507	558	609	660	711	762	814	865	916	968	**10**
20	1019	1071	1122	1174	1226	1277	1329	1381	1433	1485	**20**
30	1537	1589	1641	1693	1745	1797	1849	1902	1954	2006	**30**
40	2059	2111	2164	2216	2269	2322	2374	2427	2480	2532	**40**
50	2585	2638	2691	2744	2797	2850	2903	2956	3009	3062	**50**
60	3116	3169	3222	3275	3329	3382	3436	3489	3543	3596	**60**
70	3650	3703	3757	3810	3864	3918	3971	4025	4079	4133	**70**
80	4187	4240	4294	4348	4402	4456	4510	4564	4618	4672	**80**
90	4726	4781	4835	4889	4943	4997	5052	5106	5160	5215	**90**
100	5269	5323	5378	5432	5487	5541	5595	5650	5705	5759	**100**
110	5814	5868	5923	5977	6032	6087	6141	6196	6251	6306	**110**
120	6360	5415	6470	6525	6579	6634	6689	6744	6799	6854	**120**
130	6909	6964	7019	7074	7129	7184	7239	7294	7349	7404	**130**
140	7459	7514	7569	7624	7679	7734	7789	7844	7900	7955	**140**
150	8010	8065	8120	8175	8231	8286	8341	8396	8452	8507	**150**
160	8562	8618	8673	8728	8783	8839	8894	8949	9005	9060	**160**
170	9115	9171	9226	9282	9337	9392	9448	9503	9559	9614	**170**
180	9669	9725	9780	9836	9891	9947	10002	10057	10113	10168	**180**
190	10224	10279	10335	10390	10446	10501	10557	10612	10668	10723	**190**
200	10779	10834	10890	10945	11001	11056	11112	11167	11223	11278	**200**
210	11334	11389	11445	11501	11556	11612	11667	11723	11778	11834	**210**
220	11889	11945	12000	12056	12111	12167	12222	12278	12334	12389	**220**
230	12445	12500	12556	12611	12667	12722	12778	12833	12889	12944	**230**
240	13000	13056	13111	13167	13222	13278	13333	13389	19444	13500	**240**
250	13555	13611	13666	13722	13777	13833	13888	13944	13999	14055	**250**
260	14110	14166	14221	14277	14332	14388	14443	14499	14554	14609	**260**
270	14665	14720	14776	14831	14887	14942	14998	15053	15109	15164	**270**
280	15219	15275	15330	15386	15441	15496	15552	15607	15663	15718	**280**
290	15773	15829	15884	15940	15995	16050	16106	16161	16216	16272	**290**
300	16327	16383	16438	16493	16549	16604	16659	16715	16770	16825	**300**
310	16881	16936	16991	17046	17102	17157	17212	17268	17323	17378	**310**
320	17434	17489	17544	17599	17655	17710	17765	17820	17876	17931	**320**
330	17986	18041	18097	18152	18207	18262	18318	18373	18428	18483	**330**
340	18538	18594	18649	18704	18759	18814	18870	18925	18980	19035	**340**

Type J Thermocouple Table

Iron/Copper-Nickel, Electromotive Force as a function of temperature, E/µV

As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
350	19090	19146	19201	19256	19311	19366	19422	19477	19532	19587	**350**
360	19642	19697	19753	19808	19863	19918	19973	20028	20083	20139	**360**
370	20194	20249	20304	20359	20414	20469	20525	20580	20635	20690	**370**
380	20745	20800	20855	20911	20966	21021	21076	21131	21186	21241	**380**
390	21297	21352	21407	21462	21517	21572	21627	21683	21738	21793	**390**
400	21848	21903	21958	22014	22069	22124	22179	22234	22289	22345	**400**
410	22400	22455	22510	22565	22620	22676	22731	22786	22841	22896	**410**
420	22952	23007	23062	23117	23172	23228	23283	23338	23393	23449	**420**
430	29504	23559	23614	23670	23725	23780	23835	23891	23946	24001	**430**
440	24057	24112	24167	24223	24278	24333	24389	24444	24499	24555	**440**
450	24610	24665	24721	24776	24832	24887	24943	24998	25053	25109	**450**
460	25164	25220	25275	25331	25386	25442	25497	25553	25608	25664	**460**
470	25720	25775	25831	25886	25942	25998	26053	26109	26165	26220	**470**
480	26276	26332	26387	26443	26499	26555	26610	26666	26722	26778	**480**
490	26834	26889	26945	27001	27057	27113	27169	27225	27281	27337	**490**
500	27393	27449	27505	27561	27617	27673	27729	27785	27841	27897	**500**
510	27953	28010	28066	28122	28178	28234	28291	28347	28403	28460	**510**
520	28516	28572	28629	28685	28741	28798	28854	28911	28967	29024	**520**
530	29080	29137	29194	29250	29307	29363	29420	29477	29534	29590	**530**
540	29647	29704	29761	29818	29874	29931	29988	30045	30102	30159	**540**
550	30216	30273	30330	30387	30444	30502	30559	30616	30673	30730	**550**
560	30788	30845	30902	30960	31017	31074	31132	31189	31247	31304	**560**
570	31362	31419	31477	31535	31592	31650	31708	31766	31823	31881	**570**
580	31939	31997	32055	32113	32171	32229	32287	32345	32403	32461	**580**
590	32519	32577	32636	32694	32752	32810	32869	32927	32985	33044	**590**
600	33102	33161	33219	33278	33337	33395	33454	33513	33571	33690	**600**
610	33689	33748	33807	33866	33925	33984	34043	34102	34161	34220	**610**
620	34279	34338	34397	34457	34516	34575	34635	34694	34754	34813	**620**
630	34873	34932	34992	35051	35111	35171	35230	35290	35350	35410	**630**
640	35470	35530	35590	35650	35710	35770	35830	35890	35950	36010	**640**
650	36071	36131	36191	35252	36312	36373	36433	36494	36554	36615	**650**
660	36675	36736	36797	36858	36918	36979	37040	37101	37162	37223	**660**
670	37284	37345	37406	37467	37528	37590	37651	37712	37773	37835	**670**
680	37896	37958	38019	38081	38142	38204	38265	38327	38389	38450	**680**
690	38512	38574	38636	38698	38760	38822	38884	38946	39008	39070	**690**
700	39132	39194	39256	39318	39381	39443	39505	39568	39630	39693	**700**
710	39755	39818	39880	39943	40005	40068	40131	40193	40256	40319	**710**
720	40382	40445	40508	40570	40633	40696	40759	40822	40886	40949	**720**
730	41012	41045	41138	41201	41265	41328	41391	41455	41518	41581	**730**
740	41645	41708	41772	41835	41899	41962	42026	42090	42153	42217	**740**
750	42281	42344	42408	42472	42536	42599	42663	42727	42791	42855	**750**
760	42919	42983	43047	43111	43175	43239	43303	43367	43431	43495	**760**
770	43559	43624	43688	43752	43817	43881	43945	44010	44074	44139	**770**
780	44203	44267	44332	44396	44461	44525	44590	44655	44719	44784	**780**
790	44848	44913	44977	45042	45107	45171	45236	45301	45365	45430	**790**
800	45494	45559	45624	45688	45753	45818	45882	45947	46011	46076	**800**
810	46141	46205	46270	46334	46399	46464	46528	46593	46657	46722	**810**
820	46786	46851	46915	46980	47044	47109	47173	47238	47302	47367	**820**
830	47431	47495	47560	47624	47688	47753	47817	47881	47946	48010	**830**
840	48074	48138	48202	48267	48331	48395	48459	48523	48587	48651	**840**
850	48715	48779	48843	48907	48971	49034	49098	49162	49226	49290	**850**
860	49353	49417	49481	49544	49608	49672	49735	49799	49862	49926	**860**
870	49989	50052	50116	50179	50243	50306	50369	50432	50495	50559	**870**
880	50622	50685	50748	50811	50874	50937	51000	51063	51126	51188	**880**
890	51251	51314	51377	51439	51502	51565	51627	51690	51752	51815	**890**
900	51877	51940	52002	52064	52127	52189	52251	52314	52376	52438	**900**
910	52500	52562	52624	52686	52748	52810	52872	52934	52996	53057	**910**
920	53119	53181	53243	53304	53366	53427	53489	53550	53612	53673	**920**
930	53735	53796	53857	53919	53980	54041	54102	54164	54225	54286	**930**
940	54347	65508	54469	54530	54597	54652	54713	54773	54834	54895	**940**

Type J Thermocouple Table

Iron/Copper-Nickel, Electromotive Force as a function of temperature, E/µV
As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
950	54958	55016	55077	55138	55198	55259	55319	55380	55440	55501	**950**
960	55561	55622	55682	55742	55803	55863	55923	55983	56043	56104	**960**
970	56164	56224	56284	56344	56404	56464	56524	56584	46643	56703	**970**
980	56763	56823	56883	56942	57002	57062	57121	57181	57240	57300	**980**
990	57360	57419	57479	57538	57597	57657	57716	57776	57835	57894	**990**
1000	57953	58013	58072	58131	58190	58249	58309	58368	58427	58486	**1000**
1010	58545	58604	58663	58722	58781	58840	58899	58957	59016	59075	**1010**
1020	59134	59193	59252	59310	59369	59428	59487	59545	59604	59663	**1020**
1030	59721	59780	59838	59897	59956	60014	60073	60131	60190	60248	**1030**
1040	60307	60365	60423	60482	60540	60599	60657	60715	60774	60832	**1040**
1050	60890	60949	61007	61065	61123	61182	61240	61298	61356	61415	**1050**
1060	61473	61531	67589	61647	61705	61763	61822	61880	61938	61996	**1060**
1070	62054	62112	62170	62228	62286	62344	62402	62460	62518	62576	**1070**
1080	62634	62692	62750	62808	62866	62924	62982	63040	63098	63156	**1080**
1090	63214	63271	63329	63387	63445	63503	63561	63619	63677	63734	**1090**
1100	63792	63850	63908	63966	64024	64081	64139	64197	64255	64313	**1100**
1110	64370	64428	64486	64544	64602	64659	64717	64775	64833	64890	**1110**
1120	64948	65006	65064	65121	65179	65237	65295	65352	65410	65468	**1120**
1130	65525	65583	65641	65699	65756	65814	65872	65929	65987	66045	**1130**
1140	66102	66160	66218	66275	66333	66391	66448	66506	66564	66621	**1140**
1150	66679	66737	66794	66852	66910	66967	67025	67082	67140	67198	**1150**
1160	67225	67313	67370	67428	67486	67543	67601	67658	67716	97773	**1160**
1170	67831	67888	67946	68003	68061	68119	68176	68234	68291	68348	**1170**
1180	68406	68463	68521	68578	68636	68693	68751	68808	68865	68923	**1180**
1190	68980	69037	69095	69152	69209	69267	69324	69381	69439	69496	**1190**
1200	69553										**1200**

Type E Thermocouple Table

Nickel-Chromium/Copper-Nickel, Electromotive Force as a function of temperature, E/µV

As per Standard ASTM E230

t90/°C	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	t90/°C
-270	-9835										**-270**
-260	-9797	-9802	-9808	-9813	-9817	-9821	-9825	-9828	-9831	-9833	**-260**
-250	-9718	-9728	-9737	-9746	-9754	-6762	-9770	-9777	-9784	-9790	**-250**
-240	-9604	-9617	-9630	-9642	-9654	-9666	-9677	-9688	-9698	-9709	**-240**
-230	-9455	-9471	-9487	-9503	-9519	-9534	-9548	-9563	-9577	-9591	**-230**
-220	-9274	-9293	-9313	-9331	-9350	-9368	-9386	-9404	-9421	-9438	**-220**
-210	-9063	-9085	-9107	-9129	-9151	-9172	-9193	-9214	-9234	-9254	**-210**
-200	-8825	-8850	-8874	-8899	-8923	-8947	-8971	-8994	-9017	-9040	**-200**
-190	-8561	-8588	-8616	-8643	-8669	-8696	-8722	-8748	-8774	-8799	**-190**
-180	-8273	-8303	-8333	-8362	-8391	-8420	-8449	-8477	-8505	-8533	**-180**
-170	-7963	-7995	-8027	-8059	-8090	-8121	-8152	-8183	-8213	-8243	**-170**
-160	-7632	-7666	-7700	-7733	-7767	-7800	-7833	-7866	-7899	-7931	**-160**
-150	-7279	-7315	-7351	-7387	-7423	-7458	-7493	-7528	-7563	-7597	**-150**
-140	-6907	-6945	-6983	-7021	-7058	-7096	-7133	-7170	-7206	-7243	**-140**
-130	-6516	-6556	-6596	-6636	-6675	-6714	-6753	-6792	-6831	-6869	**-130**
-120	-6107	-6149	-6191	-6232	-6273	-6314	-6355	-6396	-6436	-6476	**-120**
-110	-5681	-5724	-5767	-5210	-5853	-5896	-5939	-5981	-6023	-6065	**-110**
-100	-5237	-5282	-5327	-5372	-5417	-5461	-5505	-5549	-5593	-5637	**-100**
-90	-4777	-4824	-4871	-4317	-4963	-5009	-5055	-5101	-5147	-5192	**-90**
-80	-4302	-4350	-4398	-4446	-4494	-4542	-4589	-4636	-4684	-4731	**-80**
-70	-3811	-3861	-3911	-3960	-4009	-4058	-4107	-4156	-4205	-4254	**-70**
-60	-3306	-3357	-3408	-3459	-3510	-3561	-3611	-3661	-3711	-3761	**-60**
-50	-2787	-2840	-2892	-2944	-2996	-3048	-3100	-3152	-3204	-3255	**-50**
-40	-2255	-2309	-2362	-2416	-2469	-2523	-2576	-2629	-2682	-2735	**-40**
-30	-1709	-1765	-1820	-1874	-1929	-1984	-2038	-2093	-2147	-2201	**-30**
-20	-1152	-1208	-1264	-1320	-1376	-1432	-1488	-1543	-1599	-1654	**-20**
-10	-582	-639	-697	-754	-811	-868	-925	-982	-1039	-1095	**-10**
0	0	-59	-117	-176	-234	-292	-350	-408	-466	-524	**0**

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
0	0	59	118	176	235	294	354	413	472	532	**0**
10	591	651	711	770	830	890	950	1010	1071	1131	**10**
20	1192	1252	1313	1373	1434	1495	1556	1617	1678	1740	**20**
30	1801	1862	1924	1986	2047	2109	2171	2233	2295	2357	**30**
40	2420	2482	2545	2607	2670	2733	2795	2858	2921	2984	**40**
50	3048	3111	3174	3238	3301	3365	3429	3492	3556	3620	**50**
60	3685	3749	3813	3877	3942	4006	4071	4136	4200	4265	**60**
70	4330	4395	4460	4526	4591	4656	4722	4788	4853	4919	**70**
80	4985	5051	5117	5183	5249	5315	5382	5448	5514	5581	**80**
90	5648	5714	5781	5848	5915	5982	6049	6117	6184	6251	**90**
100	6319	6386	6454	6522	6590	6658	6725	6794	6892	6930	**100**
110	6998	7066	7135	7203	7272	7341	7409	7478	7547	7616	**110**
120	7685	7754	7823	7892	7962	8031	8101	8170	8240	8309	**120**
130	8379	8449	8519	8589	8659	8729	8799	8869	8940	9010	**130**
140	9081	9151	9222	9292	9363	9434	9505	9576	9647	9718	**140**
150	9789	9860	9931	10003	10074	10145	10217	10288	10360	10432	**150**
160	10503	10575	10647	10719	10791	10863	10935	11007	11080	11152	**160**
170	11224	11297	11369	11442	11514	11587	11660	11733	11805	11878	**170**
180	11951	12024	12097	12170	12243	12317	12390	12463	12537	12610	**180**
190	12684	12757	12831	12904	12978	13052	13126	13199	13273	13347	**190**
200	13421	13495	13569	13644	13718	13792	13866	13941	14015	14090	**200**

Type E Thermocouple Table

Nickel-Chromium/Copper-Nickel, Electromotive Force as a function of temperature, E/μV

As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
210	14164	14239	14313	14388	14463	14537	14612	14687	14762	14837	**210**
220	14912	14987	15062	15137	15212	15287	15362	15438	15513	15588	**220**
230	15664	15739	15815	15890	15966	16041	16117	16193	16269	16344	**230**
240	16420	16496	16572	16648	16724	16800	16876	16952	17028	17104	**240**
250	17181	17257	17333	17409	17486	17562	17639	17715	17792	17868	**250**
260	17945	18021	18098	18175	18252	18328	18405	18482	18559	18636	**260**
270	18713	18790	18867	18944	19021	19098	19175	19252	19330	19407	**270**
280	19484	19561	19639	19716	19794	19871	19948	20026	20103	20181	**280**
290	20259	20336	20414	20492	20569	20647	20725	20803	20880	20958	**290**
300	21036	21114	21192	21270	21348	21426	21504	21582	21660	21739	**300**
310	21817	21895	21973	22051	22130	22208	22286	22365	22443	22522	**310**
320	22600	22678	22757	22835	22914	22993	23071	23150	23228	23307	**320**
330	23386	23464	23543	23622	23701	23780	23858	23937	24016	24095	**330**
340	24174	24253	24332	24411	24490	24569	24648	24727	24806	24885	**340**
350	24964	25044	25123	25202	25281	25360	25440	25519	25598	25678	**350**
360	25757	25836	25916	25995	26075	26154	26233	26313	26392	26472	**360**
370	26552	26631	26711	26790	26870	26950	27029	27109	27189	27268	**370**
380	27348	27428	27507	27587	27667	27747	27827	27907	27986	28066	**380**
390	28146	28226	28306	28386	28466	28546	28626	28706	28786	28866	**390**
400	28946	29026	29106	29186	29266	29346	29427	29507	29587	29667	**400**
410	29747	29827	29908	29988	30068	30148	30229	30309	30389	30470	**410**
420	30550	30630	30711	30791	30871	30952	31032	31112	31193	31273	**420**
430	31354	31434	31515	37595	31676	31756	31837	31917	31998	32078	**430**
440	32159	32239	32320	32400	32481	32562	32642	32723	32803	32884	**440**
450	32965	33045	33126	33207	33287	33368	33449	33529	33610	33691	**450**
460	33772	33852	33933	34014	34095	34175	34256	34337	34418	34498	**460**
470	34579	34660	34741	34822	34902	34983	35064	35145	35226	35307	**470**
480	35387	35468	35549	35630	35711	35792	35873	35954	36034	36115	**480**
490	36196	36244	36358	36439	36520	36601	36682	36763	36843	36924	**490**
500	37005	37086	37167	37248	37329	37410	37491	37572	37653	37734	**500**
510	37815	37896	37977	38058	38139	38220	38300	38381	38462	38543	**510**
520	38624	38705	38786	38867	38978	39029	39110	39191	39272	39353	**520**
530	39434	39515	39596	39677	39758	39839	39920	40001	40082	40163	**530**
540	40243	40324	40405	40486	40567	40648	40729	40810	40891	10972	**540**
550	41053	41134	41215	41296	41377	41457	41538	41619	41700	41781	**550**
560	41862	41943	42024	42105	42185	42266	42347	42428	42509	42590	**560**
570	42671	42751	42832	42913	42994	43075	43156	43236	43317	43398	**570**
580	43479	43560	43640	43721	43802	43883	43963	44044	44125	44206	**580**
590	44286	44367	44448	44529	44609	44690	44771	44851	44932	45013	**590**
600	45093	45174	45255	45335	45416	45497	45577	45658	45738	45819	**600**
610	45900	45980	46061	46141	46222	46302	46383	46463	46544	46624	**610**
620	46705	46785	46866	46946	47027	47107	47188	47268	47349	47429	**620**
630	47509	47590	47670	47751	47831	47911	47992	48072	48152	48233	**630**
640	48313	48393	48474	48554	48634	48715	48795	48875	48955	49035	**640**
650	49116	49196	49276	49356	49436	49517	49597	49677	49757	49837	**650**
660	49917	49997	50077	50157	50238	50318	50398	50478	50558	50638	**660**
670	50718	50798	50878	50958	51038	51118	51197	51277	51357	51437	**670**
680	51517	51597	51677	51757	51837	51916	51996	52076	52156	52236	**680**
690	52315	52395	52475	52555	52634	52714	52794	52873	52953	53033	**690**
700	53112	53192	53272	53351	53431	53510	53590	53670	53749	53829	**700**
710	53908	53988	54067	54147	54226	54306	54385	64465	54544	54624	**710**
720	54703	54782	54862	54941	55021	55100	55179	55259	55338	55417	**720**
730	55497	55576	55655	55734	55814	55893	55972	56051	56131	56210	**730**
740	56289	56368	56447	56526	56606	56685	56764	56843	56922	57001	**740**
750	57080	57159	57238	57317	57396	57475	57554	57633	57712	57791	**750**

Type E Thermocouple Table

Nickel-Chromium/Copper-Nickel, Electromotive Force as a function of temperature, E/μV
As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
760	57870	57949	58028	58107	58186	58265	58343	58422	58501	58580	**760**
770	58659	58738	58816	58895	58974	59053	59131	59210	59289	59367	**770**
780	59446	59525	59604	59682	59761	59839	59918	59997	60075	60154	**780**
790	60232	60311	60390	60468	60547	60625	60704	60782	60860	60939	**790**
800	61017	61096	61174	61253	61331	61409	61488	61566	61644	61723	**800**
810	61801	61879	61958	62036	62114	62192	62271	62349	62427	62505	**810**
820	62583	62662	62740	62818	62896	62974	63052	63130	63208	63286	**820**
830	63364	63445	63520	63598	63676	63754	63832	63910	63988	64066	**830**
840	64144	64222	64300	64377	64455	64533	64611	64689	64766	64844	**840**
850	64922	65000	65077	65155	35233	65310	65388	65465	65543	65621	**850**
860	65698	65776	65853	65931	66008	66086	66163	66241	66318	66396	**860**
870	66473	66550	66628	66705	66782	66860	66937	67014	67092	67169	**870**
880	67246	67323	67400	67478	67555	67632	67709	67786	67863	67940	**880**
890	68017	68094	68171	68248	68325	68402	68479	68556	68633	68710	**890**
900	68787	68863	68940	69017	69094	69171	69247	69324	69401	69477	**900**
910	69554	69631	69707	69784	69860	69937	70013	70090	70166	70243	**910**
920	70319	70396	70472	70548	70625	70701	70777	70854	70930	71006	**920**
930	71082	71159	71235	71311	71387	71463	71539	71615	71692	71768	**930**
940	71844	71920	71996	72072	72147	72223	72299	72375	72451	72527	**940**
950	72603	72678	72754	72830	72906	72981	73057	73133	73208	73284	**950**
960	73360	73435	73511	73586	73662	73738	73813	73889	73964	74040	**960**
970	74115	74190	74266	74341	74417	74492	74567	74643	74718	74793	**970**
980	74869	74944	75019	75095	75170	75245	75320	75395	75471	75546	**980**
990	75621	75696	75771	75847	75922	75997	76072	76147	76223	76298	**990**
1000	76373										**1000**

Type T Thermocouple Table

Copper/Copper-Nickel, Electromotive Force as a function of temperature, E/µV
As per Standard ASTM E230

t90/°C	0	-1	-2	-33	-4	-5	-6	-7	-8	-9	t90/°C
-270	-6258										**-270**
-260	-6232	-6236	-6239	-6242	-6245	-6248	-6251	-6253	-6255	-6256	**-260**
-250	-6180	-6187	-6193	-6198	-6204	-6209	-6214	-6219	-6223	-6228	**-250**
-240	-6105	-6114	-6122	-6130	-6138	-6146	-6153	-6160	-6167	-6174	**-240**
-230	-6007	-6017	-6028	-6038	-6049	-6059	-6068	-6078	-6087	-6096	**-230**
-220	-5888	-5901	-5914	-5926	-5938	-5950	-5962	-5973	-5985	-5996	**-220**
-210	-5753	-5767	-5782	-5795	-5809	-5823	-5836	-5850	-5863	-5876	**-210**
-200	-5603	-5619	-5634	-5650	-5665	-5680	-5695	-5710	-5724	-5739	**-200**
-190	-5439	-5456	-5473	-5489	-5506	-5523	-5539	-5555	-5571	-5587	**-190**
-180	-5261	-5279	-5297	-5316	-5334	-5351	-5369	-5387	-5404	-5421	**-180**
-170	-5070	-5089	-5109	-5128	-5148	-5167	-5186	-5205	-5224	-5242	**-170**
-160	-4865	-4886	-4907	-4928	-4949	-4969	-4989	-5010	-5030	-5050	**-160**
-150	-4648	-4671	-4693	-4715	-4737	-4759	-4780	-4802	-4823	-4844	**-150**
-140	-4419	-4443	-4466	-4489	-4512	-4535	-4558	-4581	-4604	-4626	**-140**
-130	-4177	-4202	-4226	-4251	-4275	-4300	-4324	-4348	-4372	-4395	**-130**
-120	-3923	-3949	-3975	-4000	-4026	-4052	-4077	-4102	-4127	-4152	**-120**
-110	-3657	-3684	-3711	-3738	-3765	-3791	-3818	-3844	-3871	-3897	**-110**
-100	-3379	-3407	-3435	-3463	-3491	-3519	-3547	-3574	-3602	-3629	**-100**
-90	-3089	-3118	-3148	-3177	-3206	-3235	-3264	-3293	-3322	-3350	**-90**
-80	-2788	-2818	-2849	-2879	-2910	-2940	-2970	-3000	-3030	-3059	**-80**
-70	-2476	-2507	-2539	-2871	-2602	-2633	-2664	-2695	-2726	-2757	**-70**
-60	-2153	-2186	-2218	-2251	-2283	-2316	-2348	-2380	-2412	-2444	**-60**
-50	-1819	-1853	-1887	-1920	-1954	-1987	-2021	-2054	-2087	-2120	**-50**
-40	-1475	-1510	-1545	-1579	-1614	-1648	-1683	-1717	-1751	-1785	**-40**
-30	-1121	-1157	-1192	-1228	-1264	-1299	-1335	-1370	-1405	-1440	**-30**
-20	-757	-794	-830	-867	-904	-940	-976	-1013	-1049	-1085	**-20**
-10	-383	-421	-459	-496	-534	-571	-608	-646	-683	-720	**-10**
0	-0	-39	-77	-116	-154	-193	-231	-269	-307	-345	**0**

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
0	0	39	78	117	156	195	234	273	312	352	**0**
10	391	431	470	510	549	589	629	669	709	749	**10**
20	790	830	870	911	951	992	1033	1074	1114	1155	**20**
30	1196	1238	1279	1320	1362	1403	1445	1486	1528	1570	**30**
40	1612	1654	1696	1738	1780	1823	1865	1908	1950	1993	**40**
50	2036	2079	2122	2165	2208	2251	2294	2338	2381	2425	**50**
60	2468	2512	2556	2600	2643	2687	2732	2776	2820	2864	**60**
70	2909	2953	2998	3043	3087	3132	3177	3222	3267	3312	**70**
80	3358	3403	3448	3494	3539	3585	3631	3677	3722	3768	**80**
90	3814	3860	3907	3953	3999	4046	4092	4138	4185	4232	**90**
100	4279	4325	4372	4419	4466	4513	4561	4608	4655	4702	**100**
110	4750	4798	4845	4893	4941	4988	5036	5084	5132	5180	**110**
120	5228	5277	5325	5373	5422	5470	5519	5567	5616	5665	**120**
130	5714	5763	5812	5861	5910	5959	6008	6057	6107	6156	**130**
140	6206	6255	6305	6355	6404	6454	6504	6554	6604	6654	**140**
150	6704	6754	6805	6855	6905	6956	7006	7057	7104	7158	**150**
160	7209	7260	7310	7361	7412	7463	7515	7566	7617	7668	**160**
170	7720	7771	7823	7874	7926	7977	8029	8081	8133	8185	**170**
180	8237	8289	8341	8393	8445	8497	8550	8602	8654	8707	**180**
190	8759	8812	8865	8917	8970	9023	9076	9129	9182	9235	**190**
200	9288	9341	9395	9448	9501	9555	9608	9662	9715	9769	**200**

Type T Thermocouple Table

Copper/Copper-Nickel, Electromotive Force as a function of temperature, E/µV
As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9	t90/°C
210	9822	9876	9930	9984	10038	10092	10146	10200	10254	10308	**210**
220	10362	10417	10471	10525	10580	10634	10689	10743	10798	10853	**220**
230	10907	10962	11017	11072	11127	11182	11237	11292	11347	11403	**230**
240											**240**
250	12013	12069	12125	12181	12237	12293	12349	12405	12461	12518	**250**
260	12574	12630	12687	12743	12799	12856	12912	12969	13026	13082	**260**
270	13139	13196	13253	13310	13366	13423	13480	13537	13595	13652	**270**
280	13709	13766	13823	13881	13938	13995	14053	14110	14168	14226	**280**
290	14283	14341	14399	14456	14514	14573	14630	14688	14746	14804	**290**
300	14862	14920	14978	15036	15095	15153	15211	15270	15328	15386	**300**
310	15445	15503	15562	15621	15679	15738	15797	15856	15914	15973	**310**
320	16032	16091	16150	16209	16268	16327	16387	16446	16505	16564	**320**
330	16624	16683	16742	16802	16861	16921	16980	17040	17100	17159	**330**
340	17219	17279	17339	17399	17458	17518	17578	17638	17698	17759	**340**
350	17819	17879	17939	17999	18060	18120	18180	18241	18301	18362	**350**
360	18422	18483	18543	18604	18665	18725	18786	18847	18908	18969	**360**
370	19030	19091	19152	19213	19274	19335	19396	19457	19518	19579	**370**
380	19641	19702	19763	19825	19886	19947	20009	20070	20132	20193	**380**
390	20255	20317	20378	20440	20502	20563	20625	20687	20748	20810	**390**
400	20875										**400**

Thermocouple W5Re-W26Re, Type C

Electromotive Force as a function of temperature, E/μV

As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9
0	0	13	27	40	54	67	81	94	108	122
10	135	149	163	176	190	204	218	231	245	259
20	273	287	301	315	329	342	356	370	385	399
30	413	427	441	455	469	483	498	512	526	540
40	555	569	583	598	612	627	641	656	670	685
50	699	714	728	743	757	772	787	801	816	831
60	846	860	875	890	905	920	934	949	964	979
70	994	1009	1024	1039	1054	1069	1084	1099	1114	1129
80	1145	1160	1175	1190	1205	1221	1236	1251	1266	1282
90	1297	1312	1328	1343	1359	1374	1389	1405	1420	1436
100	1451	1467	1483	1498	1514	1529	1545	1561	1576	1592
110	1608	1624	1639	1655	1671	1687	1702	1718	1734	1750
120	1766	1782	1798	1814	1830	1846	1862	1878	1894	1910
130	1926	1942	1958	1974	1990	2006	2023	2039	2055	2071
140	2087	2104	2120	2136	2152	2169	2185	2201	2218	2234
150	2251	2267	2283	2300	2316	2333	2349	2366	2382	2399
160	2415	2432	2449	2465	2482	2498	2515	2532	2548	2565
170	2582	2599	2615	2632	2649	2666	2682	2699	2716	2733
180	2750	2767	2784	2800	2817	2834	2851	2868	2885	2902
190	2919	2936	2953	2970	2987	3004	3021	3039	3056	3073
200	3090	3107	3124	3141	3159	3176	3193	3210	3228	3245
210	3262	3279	3297	3314	3331	3349	3366	3383	3401	3418
220	3436	3453	3470	3488	3505	3523	3540	3558	3575	3593
230	3610	3628	3645	3663	3680	3698	3716	3733	3751	3768
240	3786	3804	3821	3839	3857	3875	3892	3910	3928	3945
250	3963	3981	3999	4017	4034	4052	4070	4088	4106	4124
260	4141	4159	4177	4195	4213	4231	4249	4267	4285	4303
270	4321	4339	4357	4375	4393	4411	4429	4447	4465	4483
280	4501	4519	4537	4555	4573	4592	4610	4628	4646	4664
290	4682	4701	4719	4737	4755	4773	4792	4810	4828	4846
300	4865	4883	4901	4920	4938	4956	4974	4993	5011	5030
310	5048	5066	5085	5103	5121	5140	5158	5177	5195	5214
320	5232	5250	5269	5287	5306	5324	5343	5361	5380	5398
330	5417	5435	5454	5473	5491	5510	5528	5547	5565	5584
340	5603	5621	5640	5658	5677	5696	5714	5733	5752	5770
350	5789	5808	5827	5845	5864	5883	5901	5920	5939	5958
360	5976	5995	6014	6033	6051	6070	6089	6108	6127	6145
370	6164	6183	6202	6221	6240	6259	6277	6296	6315	6334
380	6353	6372	6391	6410	6429	6447	6466	6485	6504	6523
390	6542	6561	6580	6599	6618	6637	6656	6675	6694	6713
400	6732	6751	6770	6789	6808	6827	6846	6865	6884	6903
410	6922	6941	6961	6980	6999	7018	7037	7056	7075	7094
420	7113	7132	7152	7171	7190	7209	7228	7247	7267	7286
430	7305	7324	7343	7362	7382	7401	7420	7439	7458	7478
440	7497	7516	7535	7554	7574	7593	7612	7631	7651	7670
450	7689	7708	7728	7747	7766	7786	7805	7824	7843	7863
460	7882	7901	7921	7940	7959	7979	7998	8017	8037	8056
470	8075	8095	8114	8133	8153	8172	8191	8211	8230	8249
480	8269	8288	8308	8327	8346	8366	8385	8404	8424	8443
490	8463	8482	8502	8521	8540	8560	8579	8599	8618	8637
500	8657	8676	8696	8715	8735	8754	8774	8793	8812	8832
510	8851	8871	8890	8910	8929	8949	8968	8988	9007	9027
520	9046	9066	9085	9105	9124	9144	9163	9183	9202	9222
530	9241	9261	9280	9300	9319	9339	9358	9378	9397	9417
540	9436	9456	9475	9495	9514	9534	9553	9573	9592	9612
550	9631	9651	9670	9690	9710	9729	9749	9768	9788	9807

Thermocouple W5Re-W26Re, Type C

Electromotive Force as a function of temperature, E/μV

As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9
560	9827	9846	9866	9885	9905	9925	9944	9964	9983	10003
570	10022	10042	10061	10081	10100	10120	10140	10159	10179	10198
580	10218	10237	10257	10276	10296	10316	10335	10355	10374	10394
590	10413	10433	10452	10472	10491	10511	10531	10550	10570	10589
600	10609	10628	10648	10667	10687	10706	10726	10746	10765	10785
610	10804	10824	10843	10863	10882	10902	10921	10941	10960	10980
620	10999	11019	11038	11058	11077	11097	11117	11136	11156	11175
630	11195	11214	11234	11253	11273	11292	11312	11331	11351	11370
640	11390	11409	11429	11448	11468	11487	11507	11526	11546	11565
650	11585	11604	11624	11643	11663	11682	11702	11721	11741	11760
660	11780	11799	11818	11838	11857	11877	11896	11916	11935	11955
670	11974	11994	12013	12033	12052	12072	12091	12111	12130	12150
680	12169	12189	12208	12228	12247	12267	12286	12306	12325	12344
690	12364	12383	12403	12422	12442	12461	12481	12500	12520	12539
700	12559	12578	12597	12617	12636	12656	12675	12695	12714	12734
710	12753	12772	12792	12811	12831	12850	12870	12889	12908	12928
720	12947	12967	12986	13006	13025	13044	13064	13083	13103	13122
730	13141	13161	13180	13200	13219	13238	13258	13277	13297	13316
740	13335	13355	13374	13393	13413	13432	13452	13471	13490	13510
750	13529	13548	13568	13587	13606	13626	13645	13665	13684	13703
760	13723	13742	13761	13781	13800	13819	13839	13858	13877	13896
770	13916	13935	13954	13974	13993	14012	14032	14051	14070	14089
780	14109	14128	14147	14167	14186	14205	14224	14244	14263	14282
790	14301	14321	14340	14359	14378	14398	14417	14436	14455	14475
800	14494	14513	14532	14551	14571	14590	14609	14628	14647	14667
810	14686	14705	14724	14743	14763	14782	14801	14820	14839	14858
820	14878	14897	14916	14935	14954	14973	14993	15012	15031	15050
830	15069	15088	15107	15126	15146	15165	15184	15203	15222	15241
840	15260	15279	15298	15317	15336	15356	15375	15394	15413	15432
850	15451	15470	15489	15508	15527	15546	15565	15584	15603	15622
860	15641	15660	15679	15698	15717	15736	15755	15774	15793	15812
870	15831	15850	15869	15888	15907	15926	15945	15964	15983	16002
880	16021	16040	16058	16077	16096	16115	16134	16153	16172	16191
890	16210	16229	16248	16266	16285	16304	16323	16342	16361	16380
900	16398	16417	16436	16455	16474	16493	16511	16530	16549	16568
910	16587	16606	16624	16643	16662	16681	16699	16718	16737	16756
920	16775	16793	16812	16831	16850	16868	16887	16906	16924	16943
930	16962	16981	16999	17018	17037	17055	17074	17093	17111	17130
940	17149	17167	17186	17205	17223	17242	17261	17279	17298	17317
950	17335	17354	17373	17391	17410	17428	17447	17465	17484	17503
960	17521	17540	17558	17577	17595	17614	17633	17651	17670	17688
970	17707	17725	17744	17762	17781	17799	17818	17836	17855	17873
980	17892	17910	17929	17947	17966	17984	18002	18021	18039	18058
990	18076	18095	18113	18131	18150	18168	18187	18205	18223	18242
1000	18260	18279	18297	18315	18334	18352	18370	18389	18407	18425
1010	18444	18462	18480	18499	18517	18535	18553	18572	18590	18608
1020	18627	18645	18663	18681	18700	18718	18736	18754	18773	18791
1030	18809	18827	18845	18864	18882	18900	18918	18936	18955	18973
1040	18991	19009	19027	19045	19064	19082	19100	19118	19136	19154
1050	19172	19190	19208	19227	19245	19263	19281	19299	19317	19335
1060	19353	19371	19389	19407	19425	19443	19461	19479	19497	19515
1070	19533	19551	19569	19587	19605	19623	19641	19659	19677	19695
1080	19713	19731	19749	19767	19785	19803	19821	19839	19856	19874
1090	19892	19910	19928	19946	19964	19982	19999	20017	20035	20053
1100	20071	20089	20106	20124	20142	20160	20178	20195	20213	20231
1110	20249	20267	20284	20302	20320	20338	20355	20373	20391	20409

Thermocouple W5Re-W26Re, Type C

Electromotive Force as a function of temperature, E/µV

As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9
1120	20426	20444	20462	20479	20497	20515	20532	20550	20568	20585
1130	20603	20621	20638	20656	20674	20691	20709	20727	20744	20762
1140	20779	20797	20815	20832	20850	20867	20885	20902	20920	20938
1150	20955	20973	20990	21008	21025	21043	21060	21078	21095	21113
1160	21130	21148	21165	21183	21200	21218	21235	21253	21270	21287
1170	21305	21322	21340	21357	21375	21392	21409	21427	21444	21461
1180	21479	21496	21514	21531	21548	21566	21583	21600	21618	21635
1190	21652	21670	21687	21704	21721	21739	21756	21773	21790	21808
1200	21825	21842	21859	21877	21894	21911	21928	21946	21963	21980
1210	21997	22014	22032	22049	22066	22083	22100	22117	22135	22152
1220	22169	22186	22203	22220	22237	22254	22271	22289	22306	22323
1230	22340	22357	22374	22391	22408	22425	22442	22459	22476	22493
1240	22510	22527	22544	22561	22578	22595	22612	22629	22646	22663
1250	22680	22697	22714	22731	22748	22765	22782	22799	22815	22832
1260	22849	22866	22883	22900	22917	22934	22950	22967	22984	23001
1270	23018	23035	23052	23068	23085	23102	23119	23136	23152	23169
1280	23186	23203	23219	23236	23253	23270	23286	23303	23320	23337
1290	23353	23370	23387	23403	23420	23437	23453	23470	23487	23503
1300	23520	23537	23553	23570	23587	23603	23620	23636	23653	23670
1310	23686	23703	23719	23736	23753	23769	23786	23802	23819	23835
1320	23852	23868	23885	23901	23918	23934	23951	23967	23984	24000
1330	24017	24033	24050	24066	24083	24099	24116	24132	24148	24165
1340	24181	24198	24214	24230	24247	24263	24280	24296	24312	24329
1350	24345	24361	24378	24394	24410	24427	24443	24459	24476	24492
1360	24508	24524	24541	24557	24573	24590	24606	24622	24638	24655
1370	24671	24687	24703	24719	24736	24752	24768	24784	24800	24817
1380	24833	24849	24865	24881	24897	24913	24930	24946	24962	24978
1390	24994	25010	25026	25042	25058	25075	25091	25107	25123	25139
1400	25155	25171	25187	25203	25219	25235	25251	25267	25283	25299
1410	25315	25331	25347	25363	25379	25395	25411	25427	25443	25459
1420	25475	25490	25506	25522	25538	25554	25570	25586	25602	25618
1430	25633	25649	25665	25681	25697	25713	25729	25744	25760	25776
1440	25792	25808	25823	25839	25855	25871	25886	25902	25918	25934
1450	25949	25965	25981	25997	26012	26028	26044	26060	26075	26091
1460	26107	26122	26138	26154	26169	26185	26201	26216	26232	26248
1470	26263	26279	26294	26310	26326	26341	26357	26372	26388	26403
1480	26419	26435	26450	26466	26481	26497	26512	26528	26543	26559
1490	26574	26590	26605	26621	26636	26652	26667	26683	26698	26714
1500	26729	26744	26760	26775	26791	26806	26822	26837	26852	26868
1510	26883	26899	26914	26929	26945	26960	26975	26991	27006	27021
1520	27037	27052	27067	27083	27098	27113	27128	27144	27159	27174
1530	27190	27205	27220	27235	27250	27266	27281	27296	27311	27327
1540	27342	27357	27372	27387	27403	27418	27433	27448	27463	27478
1550	27493	27509	27524	27539	27554	27569	27584	27599	27614	27629
1560	27645	27660	27675	27690	27705	27720	27735	27750	27765	27780
1570	27795	27810	27825	27840	27855	27870	27885	27900	27915	27930
1580	27945	27960	27975	27990	28005	28020	28034	28049	28064	28079
1590	28094	28109	28124	28139	28154	28169	28183	28198	28213	28228
1600	28243	28258	28272	28287	28302	28317	28332	28346	28361	28376
1610	28391	28406	28420	28435	28450	28465	28479	28494	28509	28524
1620	28538	28553	28568	28582	28597	28612	28626	28641	28656	28670
1630	28685	28700	28714	28729	28744	28758	28773	28787	28802	28817
1640	28831	28846	28860	28875	28890	28904	28919	28933	28948	28962
1650	28977	28991	29006	29020	29035	29049	29064	29078	29093	29107
1660	29122	29136	29151	29165	29180	29194	29209	29223	29237	29252
1670	29266	29281	29295	29309	29324	29338	29353	29367	29381	29396

Thermocouple W5Re-W26Re, Type C
Electromotive Force as a function of temperature, E/μV
As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9
1680	29410	29424	29439	29453	29467	29482	29496	29510	29525	29539
1690	29553	29567	29582	29596	29610	29625	29639	29653	29667	29681
1700	29696	29710	29724	29738	29753	29767	29781	29795	29809	29823
1710	29838	29852	29866	29880	29894	29908	29922	29937	29951	29965
1720	29979	29993	30007	30021	30035	30049	30063	30077	30091	30106
1730	30120	30134	30148	30162	30176	30190	30204	30218	30232	30246
1740	30260	30274	30288	30302	30315	30329	30343	30357	30371	30385
1750	30399	30413	30427	30441	30455	30469	30482	30496	30510	30524
1760	30538	30552	30565	30579	30593	30607	30621	30635	30648	30662
1770	30676	30690	30704	30717	30731	30745	30759	30772	30786	30800
1780	30813	30827	30841	30855	30868	30882	30896	30909	30923	30937
1790	30950	30964	30978	30991	31005	31019	31032	31046	31059	31073
1800	31087	31100	31114	31127	31141	31154	31168	31182	31195	31209
1810	31222	31236	31249	31263	31276	31290	31303	31317	31330	31344
1820	31357	31371	31384	31397	31411	31424	31438	31451	31465	31478
1830	31491	31505	31518	31532	31545	31558	31572	31585	31598	31612
1840	31625	31638	31652	31665	31678	31692	31705	31718	31731	31745
1850	31758	31771	31784	31798	31811	31824	31837	31851	31864	31877
1860	31890	31903	31917	31930	31943	31956	31969	31982	31996	32009
1870	32022	32035	32048	32061	32074	32087	32101	32114	32127	32140
1880	32153	32166	32179	32192	32205	32218	32231	32244	32257	32270
1890	32283	32296	32309	32322	32335	32348	32361	32374	32387	32400
1900	32413	32426	32439	32451	32464	32477	32490	32503	32516	32529
1910	32542	32554	32567	32580	32593	32606	32619	32631	32644	32657
1920	32670	32683	32695	32708	32721	32734	32746	32759	32772	32784
1930	32797	32810	32823	32835	32848	32861	32873	32886	32899	32911
1940	32924	32937	32949	32962	32974	32987	33000	33012	33025	33037
1950	33050	33063	33075	33088	33100	33113	33125	33138	33150	33163
1960	33175	33188	33200	33213	33225	33238	33250	33263	33275	33287
1970	33300	33312	33325	33337	33350	33362	33374	33387	33399	33411
1980	33424	33436	33448	33461	33473	33485	33498	33510	33522	33535
1990	33547	33559	33571	33584	33596	33608	33620	33632	33645	33657
2000	33669	33681	33693	33706	33718	33730	33742	33754	33766	33779
2010	33791	33803	33815	33827	33839	33851	33863	33875	33887	33899
2020	33911	33923	33936	33948	33960	33972	33984	33996	34008	34019
2030	34031	34043	34055	34067	34079	34091	34103	34115	34127	34139
2040	34151	34163	34174	34186	34198	34210	34222	34234	34245	34257
2050	34269	34281	34293	34304	34316	34328	34340	34351	34363	34375
2060	34387	34398	34410	34422	34433	34445	34457	34468	34480	34492
2070	34503	34515	34527	34538	34550	34561	34573	34585	34596	34608
2080	34619	34631	34642	34654	34665	34677	34688	34700	34711	34723
2090	34734	34746	34757	34769	34780	34792	34803	34814	34826	34837
2100	34849	34860	34871	34883	34894	34905	34917	34928	34939	34951
2110	34962	34973	34984	34996	35007	35018	35029	35041	35052	35063
2120	35074	35085	35097	35108	35119	35130	35141	35152	35164	35175
2130	35186	35197	35208	35219	35230	35241	35252	35263	35274	35285
2140	35296	35307	35318	35329	35340	35351	35362	35373	35384	35395
2150	35406	35417	35428	35439	35450	35461	35472	35482	35493	35504
2160	35515	35526	35537	35547	35558	35569	35580	35591	35601	35612
2170	35623	35634	35644	35655	35666	35676	35687	35698	35708	35719
2180	35730	35740	35751	35762	35772	35783	35793	35804	35814	35825
2190	35836	35846	35857	35867	35878	35888	35899	35909	35920	35930
2200	35940	35951	35961	35972	35982	35993	36003	36013	36024	36034
2210	36044	36055	36065	36075	36086	36096	36106	36116	36127	36137
2220	36147	36157	36168	36178	36188	36198	36208	36219	36229	36239
2230	36249	36259	36269	36279	36289	36300	36310	36320	36330	36340

Thermocouple W5Re-W26Re, Type C

Electromotive Force as a function of temperature, E/μV

As per Standard ASTM E230

t90/°C	0	1	2	3	4	5	6	7	8	9
2240	36350	36360	36370	36380	36390	36400	36410	36420	36430	36440
2250	36449	36459	36469	36479	36489	36499	36509	36519	36528	36538
2260	36548	36558	36568	36577	36587	36597	36607	36616	36626	36636
2270	36645	36655	36665	36675	36684	36694	36703	36713	36723	36732
2280	36742	36751	36761	36771	36780	36790	36799	36809	36818	36828
2290	36837	36846	36856	36865	36875	36884	36894	36903	36912	36922
2300	36931									

Thermocouple W3Re-W25Re, Type D

EMF in µV with cool joint temperature at 0°C

t90/°C	0	1	2	3	4	5	6	7	8	9
0	0	10	19	29	39	48	58	68	78	88
10	98	108	118	128	138	148	158	169	179	189
20	200	210	220	231	241	252	262	273	284	294
30	305	316	327	338	348	359	370	381	392	403
40	414	426	437	448	459	471	482	493	505	516
50	527	539	551	562	574	585	597	609	620	632
60	644	656	668	680	692	704	716	728	740	752
70	764	776	789	801	813	825	838	850	863	875
80	888	900	913	925	938	951	963	976	989	1002
90	1014	1027	1040	1053	1066	1079	1092	1105	1118	1131
100	1144	1157	1171	1184	1197	1210	1224	1237	1251	1264
110	1277	1291	1304	1318	1331	1345	1359	1372	1386	1400
120	1413	1427	1441	1455	1469	1483	1497	1511	1524	1538
130	1553	1567	1581	1595	1609	1623	1637	1652	1666	1680
140	1694	1709	1723	1738	1752	1766	1781	1795	1810	1824
150	1839	1854	1868	1883	1898	1912	1927	1942	1957	1971
160	1986	2001	2016	2031	2046	2061	2076	2091	2106	2121
170	2136	2151	2166	2182	2197	2212	2227	2243	2258	2273
180	2289	2304	2319	2335	2350	2366	2381	2397	2412	2428
190	2443	2459	2475	2490	2506	2522	2537	2553	2569	2585
200	2601	2616	2632	2648	2664	2680	2696	2712	2728	2744
210	2760	2776	2792	2808	2824	2840	2857	2873	2889	2905
220	2922	2938	2954	2970	2987	3003	3019	3036	3052	3069
230	3085	3102	3118	3135	3151	3168	3184	3201	3218	3234
240	3251	3268	3284	3301	3318	3335	3351	3368	3385	3402
250	3419	3436	3452	3469	3486	3503	3520	3537	3554	3571
260	3588	3605	3622	3639	3657	3674	3691	3708	3725	3742
270	3760	3777	3794	3811	3829	3846	3863	3881	3898	3915
280	3933	3950	3968	3985	4003	4020	4037	4055	4073	4090
290	4108	4125	4143	4160	4178	4196	4213	4231	4249	4266
300	4284	4302	4320	4337	4355	4373	4391	4409	4426	4444
310	4462	4480	4498	4516	4534	4552	4570	4588	4606	4624
320	4642	4660	4678	4696	4714	4732	4750	4768	4786	4805
330	4823	4841	4859	4877	4896	4914	4932	4950	4969	4987
340	5005	5023	5042	5060	5079	5097	5115	5134	5152	5171
350	5189	5207	5226	5244	5263	5281	5300	5318	5337	5355
360	5374	5393	5411	5430	5448	5467	5486	5504	5523	5542
370	5560	5579	5598	5616	5635	5654	5673	5691	5710	5729
380	5748	5767	5785	5804	5823	5842	5861	5880	5899	5917
390	5936	5955	5974	5993	6012	6031	6050	6069	6088	6107
400	6126	6145	6164	6183	6202	6221	6240	6260	6279	6298
410	6317	6336	6355	6374	6393	6413	6432	6451	6470	6489
420	6509	6528	6547	6566	6586	6605	6624	6643	6663	6682
430	6701	6721	6740	6759	6779	6798	6817	6837	6856	6876
440	6895	6914	6934	6953	6973	6992	7012	7031	7050	7070
450	7089	7109	7128	7148	7167	7187	7206	7226	7246	7265
460	7285	7304	7324	7343	7363	7383	7402	7422	7441	7461
470	7481	7500	7520	7540	7559	7579	7599	7618	7638	7658
480	7678	7697	7717	7737	7756	7776	7796	7816	7835	7855
490	7875	7895	7915	7934	7954	7974	7994	8014	8034	8053
500	8073	8093	8113	8133	8153	8172	8192	8212	8232	8252
510	8272	8292	8312	8332	8352	8372	8391	8411	8431	8451
520	8471	8491	8511	8531	8551	8571	8591	8611	8631	8651
530	8671	8691	8711	8731	8751	8771	8791	8811	8831	8851
540	8872	8892	8912	8932	8952	8972	8992	9012	9032	9052
550	9072	9092	9113	9133	9153	9173	9193	9213	9233	9253

Thermocouple W3Re-W25Re, Type D

EMF in µV with cool joint temperature at 0°C

t90/°C	0	1	2	3	4	5	6	7	8	9
560	9274	9294	9314	9334	9354	9374	9395	9415	9435	9455
570	9475	9495	9516	9536	9556	9576	9596	9617	9637	9657
580	9677	9697	9718	9738	9758	9778	9799	9819	9839	9859
590	9880	9900	9920	9940	9961	9981	10001	10021	10042	10062
600	10082	10102	10123	10143	10163	10183	10204	10224	10244	10265
610	10285	10305	10326	10346	10366	10386	10407	10427	10447	10468
620	10488	10508	10529	10549	10569	10590	10610	10630	10651	10671
630	10691	10712	10732	10752	10773	10793	10813	10834	10854	10874
640	10895	10915	10935	10956	10976	10996	11017	11037	11058	11078
650	11098	11119	11139	11159	11180	11200	11220	11241	11261	11282
660	11302	11322	11343	11363	11383	11404	11424	11445	11465	11485
670	11506	11526	11547	11567	11587	11608	11628	11648	11669	11689
680	11710	11730	11750	11771	11791	11812	11832	11852	11873	11893
690	11914	11934	11954	11975	11995	12016	12036	12056	12077	12097
700	12118	12138	12158	12179	12199	12220	12240	12260	12281	12301
710	12322	12342	12363	12383	12403	12424	12444	12465	12485	12505
720	12526	12546	12567	12587	12608	12628	12648	12669	12689	12710
730	12730	12750	12771	12791	12812	12832	12853	12873	12893	12914
740	12934	12955	12975	12996	13016	13036	13057	13077	13098	13118
750	13139	13159	13180	13200	13220	13241	13261	13282	13302	13323
760	13343	13364	13384	13404	13425	13445	13466	13486	13507	13527
770	13548	13568	13589	13609	13630	13650	13670	13691	13711	13732
780	13752	13773	13793	13814	13842	13863	13883	13904	13924	13945
790	13965	13986	14006	14027	14047	14068	14088	14109	14129	14150
800	14170	14191	14211	14232	14252	14273	14293	14314	14334	14355
810	14375	14395	14416	14436	14457	14477	14498	14518	14539	14559
820	14580	14600	14621	14641	14662	14682	14703	14723	14744	14764
830	14784	14805	14825	14846	14866	14887	14907	14928	14948	14969
840	14989	15009	15030	15050	15071	15091	15112	15132	15152	15173
850	15193	15214	15234	15255	15275	15295	15316	15336	15357	15377
860	15398	15418	15438	15459	15479	15500	15520	15540	15561	15581
870	15602	15622	15642	15663	15683	15703	15724	15744	15765	15785
880	15805	15826	15846	15866	15887	15907	15928	15948	15968	15989
890	16009	16029	16050	16070	16090	16111	16131	16151	16172	16192
900	16212	16233	16253	16273	16294	16314	16334	16354	16375	16395
910	16415	16436	16456	16476	16497	16517	16537	16557	16578	16598
920	16618	16638	16659	16679	16699	16720	16740	16760	16780	16801
930	16821	16841	16861	16881	16902	16922	16942	16962	16983	17003
940	17023	17043	17063	17084	17104	17124	17144	17164	17185	17205
950	17225	17245	17265	17285	17306	17326	17346	17366	17386	17406
960	17427	17447	17467	17487	17507	17527	17547	17568	17588	17608
970	17628	17648	17668	17688	17708	17728	17748	17769	17789	17809
980	17829	17849	17869	17889	17909	17929	17949	17969	17989	18009
990	18029	18049	18069	18090	18110	18130	18150	18170	18190	18210
1000	18230	18250	18270	18290	18310	18330	18350	18370	18390	18410
1010	18430	18450	18469	18489	18509	18529	18549	18569	18589	18609
1020	18629	18649	18669	18689	18709	18729	18749	18768	18788	18808
1030	18828	18848	18868	18888	18908	18928	18947	18967	18987	19007
1040	19027	19047	19067	19086	19106	19126	19146	19166	19186	19205
1050	19225	19245	19265	19285	19304	19324	19344	19364	19384	19403
1060	19423	19443	19463	19482	19502	19522	19542	19561	19581	19601
1070	19621	19640	19660	19680	19700	19719	19739	19759	19778	19798
1080	19818	19837	19857	19877	19896	19916	19936	19955	19975	19995
1090	20014	20034	20054	20073	20093	20113	20132	20152	20171	20191
1100	20211	20230	20250	20269	20289	20309	20328	20348	20367	20387
1110	20406	20426	20446	20465	20485	20504	20524	20543	20563	20582

Thermocouple W3Re-W25Re, Type D

EMF in µV with cool joint temperature at 0°C

t90/°C	0	1	2	3	4	5	6	7	8	9
1120	20602	20621	20641	20660	20680	20699	20719	20738	20758	20777
1130	20797	20816	20836	20855	20875	20894	20914	20933	20952	20972
1140	20991	21011	21030	21050	21069	21088	21108	21127	21147	21166
1150	21185	21205	21224	21243	21263	21282	21301	21321	21340	21360
1160	21379	21398	21418	21437	21456	21475	21495	21514	21533	21553
1170	21572	21591	21611	21630	21649	21668	21688	21707	21726	21745
1180	21765	21784	21803	21822	21842	21861	21880	21899	21918	21938
1190	21957	21976	21995	22014	22034	22053	22072	22091	22110	22129
1200	22149	22168	22187	22206	22225	22244	22263	22283	22302	22321
1210	22340	22359	22378	22397	22416	22435	22454	22473	22493	22512
1220	22531	22550	22569	22588	22607	22626	22645	22664	22683	22702
1230	22721	22740	22759	22778	22797	22816	22835	22854	22873	22892
1240	22911	22930	22949	22968	22987	23006	23024	23043	23062	23081
1250	23100	23119	23138	23157	23176	23195	23214	23232	23251	23270
1260	23289	23308	23327	23346	23364	23383	23402	23421	23440	23459
1270	23477	23496	23515	23534	23553	23571	23590	23609	23628	23647
1280	23665	23684	23703	23722	23740	23759	23778	23797	23815	23834
1290	23853	23871	23890	23909	23928	23946	23965	23984	24002	24021
1300	24040	24058	24077	24096	24114	24133	24152	24170	24189	24208
1310	24226	24245	24263	24282	24301	24319	24338	24356	24375	24394
1320	24412	24431	24449	24468	24486	24505	24523	24542	24561	24579
1330	24598	24616	24635	24653	24672	24690	24709	24727	24746	24764
1340	24783	24801	24820	24838	24856	24875	24893	24912	24930	24949
1350	24967	24985	25004	25022	25041	25059	25078	25096	25114	25133
1360	25151	25169	25188	25206	25224	25243	25261	25280	25298	25316
1370	25335	25353	25371	25389	25408	25426	25444	25463	25481	25499
1380	25517	25536	25554	25572	25591	25609	25627	25645	25664	25682
1390	25700	25718	25736	25755	25773	25791	25809	25827	25846	25864
1400	25882	25900	25918	25936	25955	25973	25991	26009	26027	26045
1410	26063	26082	26100	26118	26136	26154	26172	26190	26208	26226
1420	26244	26262	26281	26299	26317	26335	26353	26371	26389	26407
1430	26425	26443	26461	26479	26497	26515	26533	26551	26569	26587
1440	26605	26623	26641	26659	26677	26695	26712	26730	26748	26766
1450	26784	26802	26820	26838	26856	26874	26892	26909	26927	26945
1460	26963	26981	26999	27017	27035	27052	27070	27088	27106	27124
1470	27141	27159	27177	27195	27213	27230	27248	27266	27284	27302
1480	27319	27337	27355	27373	27390	27408	27426	27444	27461	27479
1490	27497	27514	27532	27550	27567	27585	27603	27621	27638	27656
1500	27673	27691	27709	27726	27744	27762	27779	27797	27815	27832
1510	27850	27867	27885	27903	27920	27938	27955	27973	27990	28008
1520	28026	28043	28061	28078	28096	28113	28131	28148	28166	28183
1530	28201	28218	28236	28253	28271	28288	28306	28323	28341	28358
1540	28375	28393	28410	28428	28445	28463	28480	28497	28515	28532
1550	28550	28567	28584	28602	28619	28636	28654	28671	28688	28706
1560	28723	28740	28758	28775	28792	28810	28827	28844	28862	28879
1570	28896	28913	28931	28948	28965	28982	29000	29017	29034	29051
1580	29069	29086	29103	29120	29137	29155	29172	29189	29206	29223
1590	29241	29258	29275	29292	29309	29326	29343	29361	29378	29395
1600	29412	29429	29446	29463	29480	29497	29514	29532	29549	29566
1610	29583	29600	29617	29634	29651	29668	29685	29702	29719	29736
1620	29753	29770	29787	29804	29821	29838	29855	29872	29889	29906
1630	29923	29939	29956	29973	29990	30007	30024	30041	30058	30075
1640	30092	30108	30125	30142	30159	30176	30193	30210	30226	30243
1650	30260	30277	30294	30311	30327	30344	30361	30378	30394	30411
1660	30428	30445	30461	30478	30495	30512	30528	30545	30562	30579
1670	30595	30612	30629	30645	30662	30679	30695	30712	30729	30745

Thermocouple W3Re-W25Re, Type D

EMF in µV with cool joint temperature at 0°C

t90/°C	0	1	2	3	4	5	6	7	8	9
1680	30762	30779	30795	30812	30828	30845	30862	30878	30895	30911
1690	30928	30944	30961	30978	30994	31011	31027	31044	31060	31077
1700	31093	31110	31126	31143	31159	31176	31192	31209	31225	31242
1710	31258	31275	31291	31307	31324	31340	31357	31373	31389	31406
1720	31422	31439	31455	31471	31488	31504	31520	31537	31553	31569
1730	31586	31602	31618	31635	31651	31667	31684	31700	31716	31732
1740	31749	31765	31781	31797	31814	31830	31846	31862	31878	31895
1750	31911	31927	31943	31959	31976	31992	32008	32024	32040	32056
1760	32072	32088	32105	32121	32137	32153	32169	32185	32201	32217
1770	32233	32249	32265	32281	32297	32313	32329	32345	32361	32377
1780	32393	32409	32425	32441	32457	32473	32489	32505	32521	32537
1790	32553	32569	32585	32600	32616	32632	32648	32664	32680	32696
1800	32712	32727	32743	32759	32775	32791	32806	32822	32838	32854
1810	32870	32885	32901	32917	32933	32948	32964	32980	32995	33011
1820	33027	33042	33058	33074	33090	33105	33121	33136	33152	33168
1830	33183	33199	33215	33230	33246	33261	33277	33292	33308	33324
1840	33339	33355	33370	33386	33401	33417	33432	33448	33463	33479
1850	33494	33510	33525	33540	33556	33571	33587	33602	33618	33633
1860	33648	33664	33679	33694	33710	33725	33741	33756	33771	33786
1870	33802	33817	33832	33848	33863	33878	33893	33909	33924	33939
1880	33954	33970	33985	34000	34015	34030	34046	34061	34076	34091
1890	34106	34121	34136	34152	34167	34182	34197	34212	34227	34242
1900	34257	34272	34287	34302	34317	34332	34347	34362	34377	34392
1910	34407	34422	34437	34452	34467	34482	34497	34512	34527	34542
1920	34556	34571	34586	34601	34616	34631	34646	34660	34675	34690
1930	34705	34720	34734	34749	34764	34779	34793	34808	34823	34838
1940	34852	34867	34882	34896	34911	34926	34940	34955	34970	34984
1950	34999	35013	35028	35043	35057	35072	35086	35101	35115	35130
1960	35144	35159	35173	35188	35202	35217	35231	35246	35260	35275
1970	35289	35303	35318	35332	35347	35361	35375	35390	35404	35418
1980	35433	35447	35461	35476	35490	35504	35518	35533	35547	35561
1990	35575	35590	35604	35618	35632	35646	35660	35675	35689	35703
2000	35717	35731	35745	35759	35773	35787	35801	35816	35830	35844
2010	35858	35872	35886	35900	35914	35927	35941	35955	35969	35983
2020	35997	36011	36025	36039	36053	36067	36080	36094	36108	36122
2030	36136	36149	36163	36177	36191	36204	36218	36232	36246	36259
2040	36273	36287	36300	36314	36328	36341	36355	36368	36382	36396
2050	36409	36423	36436	36450	36463	36477	36490	36504	36517	36531
2060	36544	36558	36571	36585	36598	36611	36625	36638	36652	36665
2070	36678	36692	36705	36718	36731	36745	36758	36771	36784	36798
2080	36811	36824	36837	36850	36864	36877	36890	36903	36916	36929
2090	36942	36955	36969	36982	36995	37008	37021	37034	37047	37060
2100	37073	37086	37099	37111	37124	37137	37150	37163	37176	37189
2110	37202	37214	37227	37240	37253	37266	37278	37291	37304	37317
2120	37329	37342	37355	37367	37380	37393	37405	37418	37430	37443
2130	37456	37468	37481	37493	37506	37518	37531	37543	37556	37568
2140	37580	37593	37605	37618	37630	37642	37655	37667	37679	37692
2150	37704	37716	37729	37741	37753	37765	37777	37790	37802	37814
2160	37826	37838	37850	37862	37875	37887	37899	37911	37923	37935
2170	37947	37959	37971	37983	37995	38006	38018	38030	38042	38054
2180	38066	38078	38089	38101	38113	38125	38137	38148	38160	38172
2190	38183	38195	38207	38218	38230	38242	38253	38265	38276	38288
2200	38299	38311	38323	38334	38345	38357	38368	38380	38391	38403
2210	38414	38425	38437	38448	38459	38471	38482	38493	38504	38515
2220	38527	38538	38549	38560	38571	38582	38594	38605	38616	38627
2230	38638	38649	38660	38671	38682	38693	38704	38715	38725	38736

Thermocouple W3Re-W25Re, Type D

EMF in µV with cool joint temperature at 0°C

t90/°C	0	1	2	3	4	5	6	7	8	9
2240	38747	38758	38769	38780	38790	38801	38812	38823	38833	38844
2250	38855	38865	38876	38887	38897	38908	38918	38929	38940	38950
2260	38961	38971	38982	38992	39002	39013	39023	39034	39044	39054
2270	39065	39075	39085	39095	39106	39116	39126	39136	39146	39157
2280	39167	39177	39187	39197	39207	39217	39227	39237	39247	39257
2290	39267	39277	39287	39296	39306	39316	39326	39336	39345	39355
2300	39365									

Thermocouple W5Re-W20Re, Type A

EMF in µV with cool joint temperature at 0°C

t90/°C	0	1	2	3	4	5	6	7	8	9
0	0	13	25	37	49	61	73	85	97	110
10	122	134	146	159	171	184	196	209	221	234
20	246	259	271	284	297	310	322	335	348	361
30	374	386	399	412	425	438	451	464	477	491
40	504	517	530	543	557	570	583	596	610	623
50	637	650	664	677	691	704	718	731	745	758
60	772	786	799	813	827	841	855	868	882	896
70	910	924	938	952	966	980	994	1008	1022	1036
80	1050	1064	1078	1093	1107	1121	1135	1150	1164	1178
90	1193	1207	1221	1236	1250	1265	1279	1293	1308	1322
100	1337	1352	1366	1381	1395	1410	1425	1439	1454	1469
110	1483	1498	1513	1528	1542	1557	1572	1587	1602	1617
120	1632	1647	1661	1676	1691	1706	1721	1736	1751	1766
130	1782	1797	1812	1827	1842	1857	1872	1887	1903	1918
140	1933	1948	1964	1979	1994	2009	2025	2040	2055	2071
150	2086	2102	2117	2132	2148	2163	2179	2194	2210	2225
160	2241	2256	2272	2287	2303	2319	2334	2350	2365	2381
170	2397	2412	2428	2444	2459	2475	2491	2507	2522	2538
180	2554	2570	2585	2601	2617	2633	2649	2665	2680	2696
190	2712	2728	2744	2760	2776	2792	2808	2824	2840	2856
200	2872	2888	2904	2920	2936	2952	2968	2984	3000	3016
210	3032	3048	3064	3081	3097	3113	3129	3145	3161	3177
220	3194	3210	3226	3242	3259	3275	3291	3307	3324	3340
230	3356	3372	3389	3405	3421	3438	3454	3470	3487	3503
240	3519	3536	3552	3568	3585	3601	3618	3634	3650	3667
250	3683	3700	3716	3733	3749	3766	3782	3799	3815	3832
260	3848	3865	3881	3898	3914	3931	3947	3964	3980	3997
270	4013	4030	4047	4063	4080	4096	4113	4130	4146	4163
280	4179	4196	4213	4229	4246	4263	4279	4296	4313	4329
290	4346	4363	4379	4396	4413	4430	4446	4463	4480	4496
300	4513	4530	4547	4563	4580	4597	4614	4630	4647	4664
310	4681	4697	4714	4731	4748	4765	4781	4798	4815	4832
320	4849	4866	4882	4899	4916	4933	4950	4967	4983	5000
330	5017	5034	5051	5068	5085	5101	5118	5135	5152	5169
340	5186	5203	5220	5237	5253	5270	5287	5304	5321	5338
350	5355	5372	5389	5406	5423	5440	5456	5473	5490	5507
360	5524	5541	5558	5575	5592	5609	5626	5643	5660	5677
370	5694	5711	5728	5745	5762	5779	5796	5813	5830	5847
380	5864	5881	5898	5915	5932	5949	5966	5983	6000	6017
390	6034	6051	6068	6085	6102	6119	6136	6153	6170	6187
400	6204	6221	6238	6255	6272	6289	6306	6323	6340	6357
410	6374	6391	6408	6425	6442	6459	6476	6493	6510	6527
420	6544	6561	6579	6596	6613	6630	6647	6664	6681	6698
430	6715	6732	6749	6766	6783	6800	6817	6834	6851	6868
440	6885	6902	6919	6937	6954	6971	6988	7005	7022	7039
450	7056	7073	7090	7107	7124	7141	7158	7175	7192	7209
460	7226	7244	7261	7278	7295	7312	7329	7346	7363	7380
470	7397	7414	7431	7448	7465	7482	7499	7516	7533	7551
480	7568	7585	7602	7619	7636	7653	7670	7687	7704	7721
490	7738	7755	7772	7789	7806	7823	7840	7857	7874	7891
500	7908	7925	7943	7960	7977	7994	8011	8028	8045	8062
510	8079	8096	8113	8130	8147	8164	8181	8198	8215	8232
520	8249	8266	8283	8300	8317	8334	8351	8368	8385	8402
530	8419	8436	8453	8470	8487	8504	8521	8538	8555	8572
540	8589	8606	8623	8640	8657	8674	8691	8708	8725	8742
550	8759	8776	8793	8810	8827	8844	8861	8878	8895	8912

Thermocouple W5Re-W20Re, Type A

EMF in μV with cool joint temperature at 0°C

t90/°C	0	1	2	3	4	5	6	7	8	9
560	8929	8946	8963	8980	8997	9014	9031	9048	9064	9081
570	9098	9115	9132	9149	9166	9183	9200	9217	9234	9251
580	9268	9285	9302	9319	9336	9352	9369	9386	9403	9420
590	9437	9454	9471	9488	9505	9522	9538	9555	9572	9589
600	9606	9623	9640	9657	9674	9691	9707	9724	9741	9758
610	9775	9792	9809	9826	9842	9859	9876	9893	9910	9927
620	9944	9960	9977	9994	10011	10028	10045	10061	10078	10095
630	10112	10129	10146	10162	10179	10196	10213	10230	10247	10263
640	10280	10297	10314	10331	10347	10364	10381	10398	10415	10431
650	10448	10465	10482	10498	10515	10532	10549	10565	10582	10599
660	10616	10633	10649	10666	10683	10700	10716	10733	10750	10766
670	10783	10800	10817	10833	10850	10867	10884	10900	10917	10934
680	10950	10967	10984	11001	11017	11034	11051	11067	11084	11101
690	11117	11134	11151	11167	11184	11201	11217	11234	11251	11267
700	11284	11301	11317	11334	11351	11367	11384	11400	11417	11434
710	11450	11467	11484	11500	11517	11533	11550	11567	11583	11600
720	11616	11633	11650	11666	11683	11699	11716	11732	11749	11766
730	11782	11799	11815	11832	11848	11865	11882	11898	11915	11931
740	11948	11964	11981	11997	12014	12030	12047	12063	12080	12096
750	12113	12129	12146	12162	12179	12195	12212	12228	12245	12261
760	12278	12294	12311	12327	12344	12360	12376	12393	12409	12426
770	12442	12459	12475	12492	12508	12524	12541	12557	12574	12590
780	12606	12623	12639	12656	12672	12688	12705	12721	12738	12754
790	12770	12787	12803	12819	12836	12852	12869	12885	12901	12918
800	12934	12950	12967	12983	12999	13016	13032	13048	13065	13081
810	13097	13113	13130	13146	13162	13179	13195	13211	13228	13244
820	13260	13276	13293	13309	13325	13341	13358	13374	13390	13406
830	13423	13439	13455	13471	13487	13504	13520	13536	13552	13569
840	13585	13601	13617	13633	13650	13666	13682	13698	13714	13730
850	13747	13763	13779	13795	13811	13827	13843	13860	13876	13892
860	13908	13924	13940	13956	13973	13989	14005	14021	14037	14053
870	14069	14085	14101	14117	14133	14150	14166	14182	14198	14214
880	14230	14246	14262	14278	14294	14310	14326	14342	14358	14374
890	14390	14406	14422	14438	14454	14470	14486	14502	14518	14534
900	14550	14566	14582	14598	14614	14630	14646	14662	14678	14694
910	14710	14726	14742	14757	14773	14789	14805	14821	14837	14853
920	14869	14885	14901	14917	14932	14948	14964	14980	14996	15012
930	15028	15043	15059	15075	15091	15107	15123	15139	15154	15170
940	15186	15202	15218	15233	15249	15265	15281	15297	15312	15328
950	15344	15360	15376	15391	15407	15423	15439	15454	15470	15486
960	15502	15517	15533	15549	15564	15580	15596	15612	15627	15643
970	15659	15674	15690	15706	15721	15737	15753	15768	15784	15800
980	15815	15831	15847	15862	15878	15894	15909	15925	15940	15956
990	15972	15987	16003	16019	16034	16050	16065	16081	16096	16112
1000	16128	16143	16159	16174	16190	16205	16221	16236	16252	16268
1010	16283	16299	16314	16330	16345	16361	16376	16392	16407	16423
1020	16438	16454	16469	16485	16500	16515	16531	16546	16562	16577
1030	16593	16608	16624	16639	16654	16670	16685	16701	16716	16731
1040	16747	16762	16778	16793	16808	16824	16839	16854	16870	16885
1050	16901	16916	16931	16947	16962	16977	16993	17008	17023	17038
1060	17054	17069	17084	17100	17115	17130	17146	17161	17176	17191
1070	17207	17222	17237	17252	17268	17283	17298	17313	17328	17344
1080	17359	17374	17389	17405	17420	17435	17450	17465	17480	17496
1090	17511	17526	17541	17556	17571	17587	17602	17617	17632	17647
1100	17662	17677	17692	17708	17723	17738	17753	17768	17783	17798
1110	17813	17828	17843	17858	17873	17889	17904	17919	17934	17949

Thermocouple W5Re-W20Re, Type A

EMF in µV with cool joint temperature at 0°C

t90/°C	0	1	2	3	4	5	6	7	8	9
1120	17964	17979	17994	18009	18024	18039	18054	18069	18084	18099
1130	18114	18129	18144	18159	18174	18189	18203	18218	18233	18248
1140	18263	18278	18293	18308	18323	18338	18353	18368	18383	18397
1150	18412	18427	18442	18457	18472	18487	18502	18516	18531	18546
1160	18561	18576	18591	18605	18620	18635	18650	18665	18679	18694
1170	18709	18724	18739	18753	18768	18783	18798	18812	18827	18842
1180	18857	18871	18886	18901	18916	18930	18945	18960	18974	18989
1190	19004	19018	19033	19048	19062	19077	19092	19106	19121	19136
1200	19150	19165	19180	19194	19209	19224	19238	19253	19267	19282
1210	19297	19311	19326	19340	19355	19369	19384	19399	19413	19428
1220	19442	19457	19471	19486	19500	19515	19529	19544	19558	19573
1230	19587	19602	19616	19631	19645	19660	19674	19689	19703	19717
1240	19732	19746	19761	19775	19790	19804	19818	19833	19847	19862
1250	19876	19890	19905	19919	19934	19948	19962	19977	19991	20005
1260	20020	20034	20048	20063	20077	20091	20106	20120	20134	20149
1270	20163	20177	20191	20206	20220	20234	20248	20263	20277	20291
1280	20305	20320	20334	20348	20362	20377	20391	20405	20419	20433
1290	20448	20462	20476	20490	20504	20518	20533	20547	20561	20575
1300	20589	20603	20617	20631	20646	20660	20674	20688	20702	20716
1310	20730	20744	20758	20772	20786	20801	20815	20829	20843	20857
1320	20871	20885	20899	20913	20927	20941	20955	20969	20983	20997
1330	21011	21025	21039	21053	21067	21081	21095	21108	21122	21136
1340	21150	21164	21178	21192	21206	21220	21234	21248	21262	21275
1350	21289	21303	21317	21331	21345	21359	21372	21386	21400	21414
1360	21428	21442	21455	21469	21483	21497	21511	21524	21538	21552
1370	21566	21579	21593	21607	21621	21634	21648	21662	21676	21689
1380	21703	21717	21731	21744	21758	21772	21785	21799	21813	21826
1390	21840	21854	21867	21881	21895	21908	21922	21936	21949	21963
1400	21976	21990	22004	22017	22031	22044	22058	22072	22085	22099
1410	22112	22126	22139	22153	22166	22180	22194	22207	22221	22234
1420	22248	22261	22275	22288	22302	22315	22329	22342	22355	22369
1430	22382	22396	22409	22423	22436	22450	22463	22476	22490	22503
1440	22517	22530	22543	22557	22570	22584	22597	22610	22624	22637
1450	22650	22664	22677	22690	22704	22717	22730	22744	22757	22770
1460	22784	22797	22810	22823	22837	22850	22863	22877	22890	22903
1470	22916	22930	22943	22956	22969	22982	22996	23009	23022	23035
1480	23048	23062	23075	23088	23101	23114	23127	23141	23154	23167
1490	23180	23193	23206	23219	23233	23246	23259	23272	23285	23298
1500	23311	23324	23337	23350	23363	23376	23390	23403	23416	23429
1510	23442	23455	23468	23481	23494	23507	23520	23533	23546	23559
1520	23572	23585	23598	23611	23624	23637	23650	23662	23675	23688
1530	23701	23714	23727	23740	23753	23766	23779	23792	23804	23817
1540	23830	23843	23856	23869	23882	23895	23907	23920	23933	23946
1550	23959	23971	23984	23997	24010	24023	24035	24048	24061	24074
1560	24087	24099	24112	24125	24138	24150	24163	24176	24189	24201
1570	24214	24227	24239	24252	24265	24277	24290	24303	24316	24328
1580	24341	24353	24366	24379	24391	24404	24417	24429	24442	24455
1590	24467	24480	24492	24505	24518	24530	24543	24555	24568	24580
1600	24593	24606	24618	24631	24643	24656	24668	24681	24693	24706
1610	24718	24731	24743	24756	24768	24781	24793	24806	24818	24831
1620	24843	24855	24868	24880	24893	24905	24918	24930	24942	24955
1630	24967	24980	24992	25004	25017	25029	25041	25054	25066	25079
1640	25091	25103	25116	25128	25140	25152	25165	25177	25189	25202
1650	25214	25226	25239	25251	25263	25275	25288	25300	25312	25324
1660	25337	25349	25361	25373	25386	25398	25410	25422	25434	25447
1670	25459	25471	25483	25495	25507	25520	25532	25544	25556	25568

Thermocouple W5Re-W20Re, Type A

EMF in µV with cool joint temperature at 0°C

t90/°C	0	1	2	3	4	5	6	7	8	9
1680	25580	25592	25605	25617	25629	25641	25653	25665	25677	25689
1690	25701	25713	25725	25738	25750	25762	25774	25786	25798	25810
1700	25822	25834	25846	25858	25870	25882	25894	25906	25918	25930
1710	25942	25954	25966	25978	25990	26002	26014	26025	26037	26049
1720	26061	26073	26085	26097	26109	26121	26133	26145	26156	26168
1730	26180	26192	26204	26216	26228	26239	26251	26263	26275	26287
1740	26299	26310	26322	26334	26346	26357	26369	26381	26393	26405
1750	26416	26428	26440	26452	26463	26475	26487	26499	26510	26522
1760	26534	26545	26557	26569	26580	26592	26604	26615	26627	26639
1770	26650	26662	26674	26685	26697	26709	26720	26732	26743	26755
1780	26767	26778	26790	26801	26813	26825	26836	26848	26859	26871
1790	26882	26894	26905	26917	26929	26940	26952	26963	26975	26986
1800	26998	27009	27021	27032	27043	27055	27066	27078	27089	27101
1810	27112	27124	27135	27146	27158	27169	27181	27192	27204	27215
1820	27226	27238	27249	27260	27272	27283	27295	27306	27317	27329
1830	27340	27351	27363	27374	27385	27396	27408	27419	27430	27442
1840	27453	27464	27475	27487	27498	27509	27520	27532	27543	27554
1850	27565	27577	27588	27599	27610	27621	27633	27644	27655	27666
1860	27677	27688	27700	27711	27722	27733	27744	27755	27766	27778
1870	27789	27800	27811	27822	27833	27844	27855	27866	27877	27888
1880	27900	27911	27922	27933	27944	27955	27966	27977	27988	27999
1890	28010	28021	28032	28043	28054	28065	28076	28087	28098	28109
1900	28120	28130	28141	28152	28163	28174	28185	28196	28207	28218
1910	28229	28240	28250	28261	28272	28283	28294	28305	28316	28327
1920	28337	28348	28359	28370	28381	28391	28402	28413	28424	28435
1930	28445	28456	28467	28478	28488	28499	28510	28521	28531	28542
1940	28553	28564	28574	28585	28596	28606	28617	28628	28639	28649
1950	28660	28671	28681	28692	28702	28713	28724	28734	28745	28756
1960	28766	28777	28787	28798	28809	28819	28830	28840	28851	28861
1970	28872	28883	28893	28904	28914	28925	28935	28946	28956	28967
1980	28977	28988	28998	29009	29019	29030	29040	29051	29061	29071
1990	29082	29092	29103	29113	29124	29134	29144	29155	29165	29176
2000	29186	29196	29207	29217	29227	29238	29248	29259	29269	29279
2010	29290	29300	29310	29320	29331	29341	29351	29362	29372	29382
2020	29392	29403	29413	29423	29433	29444	29454	29464	29474	29485
2030	29495	29505	29515	29525	29536	29546	29556	29566	29576	29586
2040	29597	29607	29617	29627	29637	29647	29657	29667	29677	29688
2050	29698	29708	29718	29728	29738	29748	29758	29768	29778	29788
2060	29798	29808	29818	29828	29838	29848	29858	29868	29878	29888
2070	29898	29908	29918	29928	29938	29948	29958	29968	29978	29988
2080	29998	30007	30017	30027	30037	30047	30057	30067	30077	30086
2090	30096	30106	30116	30126	30136	30145	30155	30165	30175	30185
2100	30194	30204	30214	30224	30234	30243	30253	30263	30273	30282
2110	30292	30302	30311	30321	30331	30341	30350	30360	30370	30379
2120	30389	30399	30408	30418	30427	30437	30447	30456	30466	30476
2130	30485	30495	30504	30514	30524	30533	30543	30552	30562	30571
2140	30581	30590	30600	30609	30619	30629	30638	30648	30657	30666
2150	30676	30685	30695	30704	30714	30723	30733	30742	30752	30761
2160	30770	30780	30789	30799	30808	30817	30827	30836	30846	30855
2170	30864	30874	30883	30892	30902	30911	30920	30930	30939	30948
2180	30957	30967	30976	30985	30995	31004	31013	31022	31032	31041
2190	31050	31059	31069	31078	31087	31096	31105	31115	31124	31133
2200	31142	31151	31160	31170	31179	31188	31197	31206	31215	31224
2210	31233	31243	31252	31261	31270	31279	31288	31297	31306	31315
2220	31324	31333	31342	31351	31360	31369	31378	31387	31396	31405
2230	31414	31423	31432	31441	31450	31459	31468	31477	31486	31495

Thermocouple W5Re-W20Re, Type A

EMF in μV with cool joint temperature at 0°C

t90/°C	0	1	2	3	4	5	6	7	8	9
2240	31504	31513	31522	31530	31539	31548	31557	31566	31575	31584
2250	31593	31601	31610	31619	31628	31637	31646	31654	31663	31672
2260	31681	31690	31698	31707	31716	31725	31734	31742	31751	31760
2270	31769	31777	31786	31795	31803	31812	31821	31830	31838	31847
2280	31856	31864	31873	31882	31890	31899	31908	31916	31925	31933
2290	31942	31951	31959	31968	31976	31985	31994	32002	32011	32019
2300	32028	32036	32045	32054	32062	32071	32079	32088	32096	32105
2310	32113	32122	32130	32139	32147	32156	32164	32172	32181	32189
2320	32198	32206	32215	32223	32232	32240	32248	32257	32265	32274
2330	32282	32290	32299	32307	32315	32324	32332	32340	32349	32357
2340	32365	32374	32382	32390	32399	32407	32415	32424	32432	32440
2350	32448	32457	32465	32473	32482	32490	32498	32506	32515	32523
2360	32531	32539	32547	32556	32564	32572	32580	32588	32597	32605
2370	32613	32621	32629	32637	32646	32654	32662	32670	32678	32686
2380	32694	32702	32711	32719	32727	32735	32743	32751	32759	32767
2390	32775	32783	32791	32800	32808	32816	32824	32832	32840	32848
2400	32856	32864	32872	32880	32888	32896	32904	32912	32920	32928
2410	32936	32944	32952	32960	32968	32976	32984	32992	33000	33007
2420	33015	33023	33031	33039	33047	33055	33063	33071	33079	33087
2430	33095	33102	33110	33118	33126	33134	33142	33150	33158	33166
2440	33173	33181	33189	33197	33205	33213	33221	33228	33236	33244
2450	33252	33260	33268	33275	33283	33291	33299	33307	33314	33322
2460	33330	33338	33346	33353	33361	33369	33377	33385	33392	33400
2470	33408	33416	33423	33431	33439	33447	33454	33462	33470	33478
2480	33485	33493	33501	33509	33516	33524	33532	33540	33547	33555
2490	33563	33570	33578	33586	33594	33601	33609	33617	33625	33632
2500	33640									

Temperature to EMF Tables and polynomial Coefficients of Thermocouples

The international standard IEC 584-1, in Europe EN 60 584-1, gives the relationship between the temperature t_{90}in °C and the thermal EMF E in µV for the mathematical calculation polynomial expression of higher degree are divides in several ranges, than the coefficients a has to be substituted by the C and D.

$$t_{90} = \sum_{i=0}^{i} A_i * E^i$$

For the thermocouple type K (NiCr-Ni), Following polynomial is used for the range from 0 to 1372°C:

$$E = B_0 + \sum B_i (t_{90})_I + C_0 \exp[C_i (t_{90} - 126,9686)^2]$$

for the daily use in calibration laboratories the inverse function is useful. The inverse function calculates the temperature t_{90}in °C from the Thermal EMF in µV. The inverse function is an approximation of higher degree and has the uncertainty given in the coefficient tables. The inverse function has the following common form:

$$E = \sum_{i=0}^{i} A_i \, (t_{90})^i$$

If the polynomial are divides in several ranges, Than the coefficient A has to be substituted by the coefficients C and D.

Important Notes :

For thermocouples type C (W5%Re-W26%Re) and D (W3%Re-W25%Re) the thermal EMF has the dimension mV (1 mV = 1000 µV)!

The inverse functions of types A, C and D have, to the date of this booklet, no official uncertainties for the approximations. It can be taken in account, the with quite high probability the uncertainty is significantly below 1 K.

In the appendix the polynomial coefficients for the non noble metal TC's are given first followed by the noble metal TC's. The polynomial coefficients for the refractory (high temperature) TC's are given at the end.

The following tables are calculated using the program MICROSOFT® EXCEL® in the version 2007 using the coefficients given herein. No reliability will be taken for mistakes in calculation. If in doubt, please use the official tables in the a.m. standard.

This booklet in no case substitutes the official printed version of the IEC 584-1 standard.

Thermocouple Type E (NiCr-CuNi)

Conversion: Temperature [°C] into EMF [µV]
Range : 270°C to 0°C
A(0) = 0
A(1) = 58.665508708
A(2) = 0.045410977124
A(3) = -0.00077998048686
A(4) = -0.000025800160843
A(5) = -5.9452583057E-07
A(6) = -9.3214058667E-09
A(7) = -1.0287605534E-10
A(8) = -8.0370123621E-13
A(9) = -4.3979497391E-15
A(10) = -1.6414776355E-17
A(11) = -3.9673619516E-20
A(12) = -5.5827328721E-23
A(13) = -3.4657842013E-26

Range : 0°C to 1000°C
B(0) = 0
B(1) = 58.66550871
B(2) = 0.045032275582
B(3) = 0.000028908407212
B(4) = -3.3056896652E-07
B(5) = 6.502440327E-10
B(6) = -1.9197495504E-13
B(7) = -1.2536600497E-15
B(8) = 2.1489217569E-18
B(9) = -1.4388041782E-21
B(10) = 3.5960899481E-25

Conversion: EMF [µV] into Temperature [°C]]
Range : 8825 µV to 0 µV
A(0) = 0
A(1) = 0.01697288
A(2) = -0.0000004351497
A(3) = -1.5859697E-10
A(4) = -9.2502871E-14
A(5) = -2.608431E-17
A(6) = -4.1360199E-21
A(7) = -3.403403E-25
A(8) = -1.156489E-29

Range : 0 µV to 76373 µV
Dim B(9) As Double
B(0) = 0
B(1) = 0.017057035
B(2) = -0.00000023301759
B(3) = 6.5435585E-12
B(4) = -7.3562749E-17
B(5) = -1.7896001E-21
B(6) = 8.4036165E-26
B(7) = -1.3735879E-30
B(8) = 1.0629823E-35
B(9) = -3.2447087E-41
Uncertainty : +0.016/-0.012°C

Thermocouple Type J (Fe-CuNi)

Conversion: Temperature [°C] to EMF [µV]
Range : 210°C to 760°C
A(0) = 0
A(1) = 50.381187815
A(2) = 0.03047583693
A(3) = -0.00008568106572
A(4) = 1.3228195295E-07
A(5) = -1.7052958337E-10
A(6) = 2.0948090697E-13
A(7) = -1.2538395336E-16
A(8) = 1.5631725697E-20

Range : 760°C to 1200°C
B(0) = 296456.25681
B(1) = -1497.6127786
B(2) = 3.1787103924
B(3) = -0.0031847686701
B(4) = 1.5720819004E-06
B(5) = -3.0691369056E-10

Conversion: EMF [µV] into Temperature [°C]
Range : 8095 µV to 0 µV
A(0) = 0
A(1) = 0.019528268
A(2) = -0.0000012286185
A(3) = -1.0752178E-09
A(4) = -5.9086933E-13
A(5) = -1.7256713E-16
A(6) = -2.8131513E-20
A(7) = -2.396337E-24
A(8) = -8.3823321E-29

Range : 0 µV to 42919 µV
B(0) = 0
B(1) = 0.01978425
B(2) = -0.0000002001204
B(3) = 1.036969E-11
B(4) = -2.549687E-16
B(5) = 3.585153E-21
B(6) = -5.344285E-26
B(7) = 5.09989E-31

Range : 42919 µV to 69553 µV
C(0) = -3113.58187
C(1) = 0.300543684
C(2) = -0.0000099477323
C(3) = 1.7027663E-10
C(4) = -1.43033468E-15
C(5) = 4.73886084E-21
Uncertainty : +0.024/-0.037°C

Thermocouple Type K (NiCr-Ni)

Conversion:Temperature [°C] into EMF [µV]
Range : 270°C to 0°C
A(0) = 0
A(1) = 39.450128025
A(2) = 0.023622373598
A(3) = -0.00032858906784
A(4) = -4.9904828777E-06
A(5) = -6.7509059173E-08
A(6) = -5.7410327428E-10
A(7) = -3.1088872894E-12
A(8) = -1.0451609365E-14
A(9) = -1.9889266878E-17
A(10) = -1.6322697486E-20

Range : 0°C to 1372°C
B(0) = -17.600413686
B(1) = 38.921204975
B(2) = 0.018558770032
B(3) = -0.000099457592874
B(4) = 3.1840945719E-07
B(5) = -5.6072844889E-10
B(6) = 5.6075059059E-13
B(7) = -3.2020720003E-16
B(8) = 9.7151147152E-20
B(9) = -1.2104721275E-23
C(0) = 118.5976
C(1) = -0.0001183432

Conversion: EMF [µV] into Temperature [°C]
Range : 5891 µV to 0 µV
A(0) = 0
A(1) = 0.025173462
A(2) = -0.0000011662878
A(3) = -1.0833638E-09
A(4) = -8.977354E-13
A(5) = -3.7342377E-16
A(6) = -8.6632643E-20
A(7) = -1.0450598E-23
A(8) = -5.1920577E-28

Range : 0 µV to 20644 µV
B(0) = 0
B(1) = 0.02508355
B(2) = 0.00000007860106
B(3) = -2.503131E-10
B(4) = 8.31527E-14
B(5) = -1.228034E-17
B(6) = 9.804036E-22
B(7) = -4.41303E-26
B(8) = 1.057734E-30
B(9) = -1.052755E-35

Range : 20644 µV to 54886 µV
C(0) = -131.8058
C(1) = 0.04830222
C(2) = -0.000001646031
C(3) = 5.464731E-11
C(4) = -9.650715E-16
C(5) = 8.802193E-21
C(6) = -3.11081E-26
Uncertainty : +0.054/-0.046°C

Thermocouple Type L (Fe-CuNi)

Conversion: Temperature [°C] to EMF [µV]

Range : 200°C to 900°C
A(0) = 0
A(1) = 51.71089598
A(2) = 0.02787113678
A(3) = -0.0001043996689
A(4) = 3.685483483E-07
A(5) = -8.751008267E-10
A(6) = -2.082014998E-12
A(7) = 2.178467727E-14
A(8) = -6.589869604E-17
A(9) = 1.036698719E-19
A(10) = -9.121218528E-23
A(11) = 4.247340152E-26
A(12) = -8.14181198E-30

The polynomial coefficients for thermocouple type L (Fe-CuNi) are proposed by R.L.de Groot from Van Swinden Laboratory (VSL) at NMI in Delft/The Netherlands. They are commonly accepted for conversion temperatur into EMF and vice versa.
The primarily German standard DIN 43 710 did not contain poli - nomial coefficients The standard was withdrawn in October 1997.
Conversion: EMF [µV] into Temperature [°C]

Range : 8167 µV to 53148 µV
A(0) = 0
A(1) = 51.71089598
A(2) = 0.02787113678
A(3) = -0.0001043996689
A(4) = 3.685483483E-07
A(5) = -8.751008267E-10
A(6) = -2.082014998E-12
A(7) = 2.178467727E-14
A(8) = -6.589869604E-17
A(9) = 1.036698719E-19
A(10) = -9.121218528E-23
A(11) = 4.247340152E-26
A(12) = -8.14181198E-30
Uncertainty : +0.031/-0.040°C

Thermocouple Type N (NiCrSi-NiSi)

Conversion: Temperature [°C] into EMF [µV]
Range : 210°C to 0°C
A(0) = 0
A(1) = 26.159105962
A(2) = 0.010957484228
A(3) = -0.000093841111554
A(4) = -4.6412039759E-08
A(5) = -2.6303367716E-09
A(6) = -2.2653438003E-11
A(7) = -7.6089300791E-14
A(8) = -9.3419667835E-17

Range : 0°C to 1300°C
B(0) = 0
B(1) = 25.929394601
B(2) = 0.01571014188
B(3) = 0.000043825627237
B(4) = -2.5261169794E-07
B(5) = 6.4311819339E-10
B(6) = -1.0063471519E-12
B(7) = 9.9745338992E-16
B(8) = -6.0863245607E-19
B(9) = 2.0849229339E-22
B(10) = -3.0682196151E-26

Conversion: EMF [µV] into Temperature [°C]
Range : 3990 µV to 0 µV
A(0) = 0
A(1) = 0.038436847
A(2) = 0.0000011010485
A(3) = 5.2229312E-09
A(4) = 7.2060525E-12
A(5) = 5.8488586E-15
A(6) = 2.7754916E-18
A(7) = 7.7075166E-22
A(8) = 1.1582665E-25
A(9) = 7.3138868E-30

Range : 0 µV to 20613 µV
B(0) = 0
B(1) = 0.0386896
B(2) = -0.00000108267
B(3) = 4.70205E-11
B(4) = -2.12169E-18
B(5) = -1.17272E-19
B(6) = 5.3928E-24
B(7) = -7.98156E-29

Range : 20613 µV to 47513 µV
C(0) = 19.72485
C(1) = 0.03300943
C(2) = -0.0000003915159
C(3) = 9.855391E-12
C(4) = -1.274371E-16
C(5) = 7.767022E-22
Uncertainty : +0.021/-0.039°C

Thermocouple Type T (Cu-CuNi)

Conversion: Temperature [°C] to EMF [µV]
Range : 3990 µV to 0 µV
A(0) = 0
A(1) = 0.038436847
A(2) = 0.0000011010485
A(3) = 5.2229312E-09
A(4) = 7.2060525E-12
A(5) = 5.8488586E-15
A(6) = 2.7754916E-18
A(7) = 7.7075166E-22
A(8) = 1.1582665E-25
A(9) = 7.3138868E-30

Range : 0 µV to 20613 µV
B(0) = 0
B(1) = 0.0386896
B(2) = -0.00000108267
B(3) = 4.70205E-11
B(4) = -2.12169E-18
B(5) = -1.17272E-19
B(6) = 5.3928E-24
B(7) = -7.98156E-29

Range : 20613 µV to 47513 µV
C(0) = 19.72485
C(1) = 0.03300943
C(2) = -0.0000003915159
C(3) = 9.855391E-12
C(4) = -1.274371E-16
C(5) = 7.767022E-22

Conversion: EMF [µV] into Temperature [°C]
Range : 5603 µV to 0 µV
A(1) = 0.025949192
A(2) = -0.00000021316967
A(3) = 7.9018692E-10
A(4) = 4.2527777E-13
A(5) = 1.3304473E-16
A(6) = 2.0241446E-20
A(7) = 1.2668171E-24

Range : 0 µV to 20872 µV
B(0) = 0
B(1) = 0.025928
B(2) = -0.0000007602961
B(3) = 4.637791E-11
B(4) = -2.165394E-15
B(5) = 6.048144E-20
B(6) = -7.293422E-25

Uncertainty : +0.025/-0.025°C

Thermocouple Type B (Pt30%Rh-Pt6%Rh)

Conversion: Temperature [°C] into EMF [µV]
Remark :
Thermocouples type B are normally not used at temperatures below 250°C.

Range : 0°C to 630.615°C
A(0) = 0
A(1) = -0.24650818346
A(2) = 0.0059040421171
A(3) = -1.3257931636E-06
A(4) = 1.5668291901E-09
A(5) = -1.694452924E-12
A(6) = 6.2990347094E-16

Range : 630.615°C to 1820°C
B(0) = -3893.8168621
B(1) = 28.57174747
B(2) = -0.084885104785
B(3) = 0.00015785280164
B(4) = -1.6835344864E-07
B(5) = 1.1109794013E-10
B(6) = -4.4515431033E-14
B(7) = 9.8975640821E-18
B(8) = -9.3791330289E-22

Conversion: EMF [µV] into Temperature [°C]
Remark :
The inverse function starts at 291 µV (~250°C). Below that border the deviation from the base function becomes significant high.

Range : 291 µV to 2431 µV
A(0) = 98.423321
A(1) = 0.699715
A(2) = -0.00084765304
A(3) = 0.0000010052644
A(4) = -8.3345952E-10
A(5) = 4.5508542E-13
A(6) = -1.5523037E-16
A(7) = 2.988675E-20
A(8) = -2.474286E-24

Uncertainty : +0.026/-0.020°C

Range : 2431 µV to 13820 µV
B(0) = 213.15071
B(1) = 0.28510504
B(2) = -0.000052742887
B(3) = 9.9160804E-09
B(4) = -1.2965303E-12
B(5) = 1.119587E-16
B(6) = -6.0625199E-21
B(7) = 1.8661696E-25
B(8) = -2.4878585E-30

Uncertainty : +0.012/-0.007°C

Thermocouple Type R (Pt13%Rh-Pt)

Conversion : EMF [µV] into Temperature [°C]

Range : -50°C to 1064.18°C
A(0) = 0
A(1) = 5.28961729765
A(2) = 0.0139166589782
A(3) = -2.38855693017E-05
A(4) = 3.56916001063E-08
A(5) = -4.62347666298E-11
A(6) = 5.00777441034E-14
A(7) = -3.73105886191E-17
A(8) = 1.5771682367E-20
A(9) = -2.81038625251E-24

Range : 1064.18°C to 1664.5°C
B(0) = 2951.57925316
B(1) = -2.52061251332
B(2) = 0.0159564501865
B(3) = -7.64085947576E-06
B(4) = 2.05305291024E-09
B(5) = -2.93359668173E-13

Range : 1664.5°C to 1768.1°C
C(0) = 152232.118209
C(1) = -268.819888545
C(2) = 0.171280280471
C(3) = -3.45895706453E-05
C(4) = -9.34633971046E-12

Conversion : EMF [µV] into Temperature [°C]
Range : - 226 µV to 1923 µV
A(0) = 0
A(1) = 0.1889138
A(2) = -0.00009383529
A(3) = 0.00000013068619
A(4) = -0.000000000227035
A(5) = 3.5145659E-13
A(6) = -3.89539E-16
A(7) = 2.8239471E-19
A(8) = -1.2607281E-22
A(9) = 3.1353611E-26
A(10) = -3.3187769E-30

Uncertainty : +0.018/-0.011°C

Range : 1923 µV to 11361 µV
B(0) = 13.34584505
B(1) = 0.1472644573
B(2) = -0.00001844024844
B(3) = 4.031129726E-09
B(4) = -6.24942836E-13
B(5) = 6.468412046E-17
B(6) = -4.458750426E-21
B(7) = 1.994710149E-25
B(8) = -5.31340179E-30
B(9) = 6.481976217E-35

Range : 11361 µV to 19739 µV
C(0) = -81.99599416
C(1) = 0.1553962042
C(2) = -0.000008342197663
C(3) = 4.279433549E-10
C(4) = -1.19157791E-14
C(5) = 1.492290091E-19

Range : 19739 µV to 21103 µV
D(0) = 34061.77836
D(1) = -7.023729171
D(2) = 0.0005582903813
D(3) = -1.952394635E-08
D(4) = 2.560740231E-13

Uncertainty: +0.005/-0.003°C

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Thermocouple Type S (Pt10%Rh-Pt6)

Conversion: Temperature [°C] into EMF [µV]
Range : -50°C to 1064.18°C
A(0) = 0
A(1) = 5.40313308631
A(2) = 0.012593428974
A(3) = -2.32477968689E-05
A(4) = 3.22028823036E-08
A(5) = -3.31465196389E-11
A(6) = 2.55744251786E-14
A(7) = -1.25068871393E-17
A(8) = 2.71443176145E-21

Range : 1064.18°C to 1664.5°C
B(0) = 1329.00444085
B(1) = 3.34509311344
B(2) = 0.00654805192818
B(3) = -1.64856259209E-06
B(4) = 1.29989605174E-11

Range : 1664.5°C to 1768.1°C
C(0) = 146628.232636
C(1) = -258.430516752
C(2) = 0.163693574641
C(3) = -3.30439046987E-05
C(4) = -9.43223690612E-12

Conversion: EMF [µV] into Temperature [°C]
Range : -235 µV to 1874 µV
A(0) = 0
A(1) = 0.18494946
A(2) = -0.0000800504062
A(3) = 0.00000010223743
A(4) = -1.52248592E-10
A(5) = 1.88821343E-13
A(6) = -1.59085941E-16
A(7) = 8.2302788E-20
A(8) = -2.34181944E-23
A(9) = 2.7978626E-27
Uncertainty : +0.020/-0.011°C

Range : 1874 µV to 10332 µV
B(0) = 12.91507177
B(1) = 0.1466298863
B(2) = -0.00001534713402
B(3) = 3.145945973E-09
B(4) = -4.163257839E-13
B(5) = 3.187963771E-17
B(6) = -1.2916375E-21
B(7) = 2.183475087E-26
B(8) = -1.447379511E-31
B(9) = 8.211272125E-36

Range : 10332 µV to 17536 µV
C(0) = -80.87801117
C(1) = 0.1621573104
C(2) = -0.000008536869453
C(3) = 4.719686976E-10
C(4) = -1.441693666E-14
C(5) = 2.08161889E-19

Range : 17536 µV to 18694 µV
D(0) = 53338.75126
D(1) = -12.35892298
D(2) = 0.001092657613
D(3) = -4.265693686E-08
D(4) = 6.24720542E-13
Uncertainty : +0.006/-0.009°C

Thermocouple Type C (W5%Re-W26%Re)

Conversion: Temperature [°C] to EMF [µV]
Result : EMF in Millivolt !

Remark : Refractory (W-Re) thermocouples are normally not used at temperatures below 1000°C.

Range : 0°C to 630.615°C
A(0) = 0
A(1) = 13.406032
A(2) = 0.011924992
A(3) = -0.0000079806354
A(4) = -5.0787515E-09
A(5) = 1.3164197E-11
A(6) = -7.9197332E-15

Range : 630.615°C to 2315°C
B(0) = 405.28823
B(1) = 11.509355
B(2) = 0.015696453
B(3) = -0.000013704412
B(4) = 5.2290873E-09
B(5) = -9.2082758E-13
B(6) = 4.5245112E-17

Conversion: EMF [mV] into Temperature [°C]
Input : EMF in Millivolt !

Remark : Refractory (W-Re) thermocouples are normally not used at temperatures below 1000°C.

Range : 0 mV to 37.070 mV
A(0) = 0
A(1) = 0.0741247326
A(2) = -0.00000428082813
A(3) = 5.2113892E-10
A(4) = 4.57487201E-14
A(5) = 2.80578284E-18
A(6) = -1.13145137E-22
A(7) = 2.85489684E-27
A(8) = -4.07643828E-32
A(9) = 2.51358071E-37

Thermocouple Type D (W3%Re-W25%Re)

Conversion: Temperature [°C] into EMF [µV]

Result : EMF in Millivolt !

Remark :
Refractory (W-Re) thermocouples are normally not used at tempe- ratures below 1000 °C.

Range : 0°C to 783°C
A(0) = 0
A(1) = 0.0095821929
A(2) = 0.000020068371
A(3) = -0.000000013786121
A(4) = -1.1620542E-11
A(5) = 3.98753E-14
A(6) = -4.2429757E-17
A(7) = 1.6821225E-20

Range : 783°C to 2315°C
B(0) = 2.2097354
B(1) = -0.0014500612
B(2) = 0.000042898234
B(3) = -0.000000042816409
B(4) = 2.4132609E-11
B(5) = -8.1885541E-15
B(6) = 1.5873209E-18
B(7) = -1.4320975E-22

Conversion: EMF [µV] into Temperature [°C]

Input : EMF in Millivolt !

Remark :
Refractory (W-Re) thermocouples are normally not used at temperatures below 1000°C.

Range : 0 mV to 39.508 mV
A(0) = 0
A(1) = 101.387139
A(2) = -15.1768486
A(3) = 3.13787524
A(4) = -0.446716692
A(5) = 0.0427451436
A(6) = -0.002749759
A(7) = 0.000118845993
A(8) = -0.00000339703227
A(9) = 6.15028058E-08
A(10) = -6.38332695E-10
A(11) = 2.89238418E-12

Thermocouple Type A (W5%Re-W20%Re)

Conversion: Temperature [°C] into EMF [µV]

Result : EMF in Millivolt !

Remark :
Refractory (W-Re) thermocouples are normally not used at temperatures below 1000°C.

Range : 0°C to 2500°C
A(0) = 0.71564735
A(1) = 11.951905
A(2) = 0.016672625
A(3) = -0.000028287807
A(4) = 0.000000028397839
A(5) = -1.8505007E-11
A(6) = 7.3632123E-15
A(7) = -1.6148878E-18
A(8) = 1.4901679E-22

Conversion: EMF [µV] into Temperature [°C]

Input : EMF in Millivolt !

Remark :
Refractory (W-Re) thermocouples are normally not used at temperatures below 1000°C.

Range : 0 µV to 33640 µV
A(0) = 0.0009643027
A(1) = 0.079495086
A(2) = -0.000004999031
A(3) = 6.341776E-10
A(4) = -4.7440967E-14
A(5) = 2.1811337E-18
A(6) = -5.8324228E-23
A(7) = 8.2433725E-28
A(8) = -4.592848E-31

CORROSIVE SERVICE GUIDE

CORROSIVE AGENT	Deg C	CONC %	RECOMMENDED MATERIAL
Acetic Acid (Glacial)	200	ALL	316 SS
Acetic Acid	140	80%	Hast. C
	200	50%	316 SS
	140	80%	Carp. 20*
Acetic Anhydride	130	ALL	Hast. C
	200	ALL	316 SS*
Acetone	200	ALL	316 SS
Acetylene	200	ALL	304 SS
Alcohol, Ethyl	90	ALL	Hast. C
	200	ALL	316 SS*
Aluminium Chloride (Aqueous)	140	ALL	Hast. B
	140	ALL	Nickel *
Aluminium Nitrate (Saturated)	90	ALL	446 SS
	90	ALL	316 SS*
Aluminium Salfate (Saturated)	90	ALL	Titanium
	90	ALL	316 SS*
Ammonia (Anhydrous)	290	ALL	316 SS
Ammonia (Gas)	90	ALL	304 SS
Ammonium Chloride	90	ALL	Titanium
	290	ALL	Nickel *
	70	50%	Nickel
Ammonium Hydroxide	30	ALL	Steel
	80	ALL	Steel *
Ammonium Nitrate	90	ALL	Carp.20
Ammonium Sulfate	90	SAT	Hast. B
	140	SAT	304 SS*
	90	10-40%	Titanium
	200	10-40%	316 SS*
Amyl Acetate	140	ALL	304 SS
Aniline	250	ALL	304 SS
Barium Chloride (Saturated)	90	ALL	Hast. C
	290	ALL	Inconel *
Barium Hydroxide (Saturated)	100	50%	Carp. 20
	200	ALL	316 SS*
Beer	90		SS 304
Benzene (Benzol)	100	ALL	Carp. 20
	100	ALL	304 SS*
Benzoic Acid	200	ALL	Titanium
	200	ALL	304 SS*
Black Liquor	240	ALL	TFE
	190	ALL	FEP
	90	ALL	Carp. 20 *
Bleach (Active Chlorine)	60	12.50%	Hast. C
Borax	200	ALL	316 SS
Boric Acid	290	ALL	Hast C
	90	ALL	Nickel *
Brine Acid	60	ALL	Hast. C
	30	ALL	Brass *
Bromine (Liquid)	290	ALL	Tantalum
	90	ALL	Aluminum *
Butane	170	ALL	Steel
Butyl Acetate	90	ALL	Titanium
	190	ALL	316 SS *
Butyl Alcohol	200	ALL	316 SS
Butyric Acid	140	ALL	Carp. 20

CORROSIVE AGENT	Deg C	CONC %	RECOMMENDED MATERIAL
Calcium Hydroxide	90	50%	Hast. C
	90	SAT	304 SS *
Carbonic Acid	290	ALL	Carp. 20
	170	ALL	316 SS*
Carbonic Dioxide (Dry)	430	ALL	Brass
Carbonated Beverages	100	ALL	304 SS
Carbon Disulfide	90	ALL	Titanium
	200	ALL	316 SS *
Carbon Tetrachloride	90	ALL	304 SS
Chlorine (Gas)	90	ALL	Monel
	200	ALL	316 SS*
Chlorine (Gas - Moist)	70	ALL	Hast. C
Chloroform Acid	180	ALL	Hast. B
Chloroform	90	ALL	Nickel
	90	ALL	Carp. 20 *
Chromic Acid	90	50%	Titanium
	90	50%	Hast. C*
Citric Acid	130	ALL	Hast. C*
	90	ALL	Carp. 20*
Copper Cloride	90	ALL	Titanium
	90	ALL	Hast. C*
Copper Nitrate 300 ALL 304 SS	150	ALL	304 SS
Copper Sulfate 200 ALL Hast. C	90	ALL	Hast. C
	200	ALL	316 SS*
Corn Oil	240	ALL	TFE
	190	ALL	FEP
	170	ALL	316 SS*
Crude Oil	90	ALL	304 SS*
Cyanogen Gas	240	ALL	TFE
	190	ALL	FEP
	170	ALL	316 SS*
Ether	90	ALL	304 SS
Ethyl Acetate	90	ALL	Titanium
	200	ALL	316 SS*
Ethyl Chloride (Dry)	290	ALL	316 SS
Ethylene Glycol	90	ALL	Carp. 20
	90	ALL	304 SS*
Ethylene Oxide	20	ALL	Hast. C
	200	ALL	316 SS*
Fatty Acids	200	ALL	316 SS
Ferric Chloride	140	ALL	Titanium
	30	ALL	Hast. C*
Ferric Sulfate	50	ALL	Carp. 20
	90	ALL	316 SS
Ferrous Sulfate	30	ALL	Titanium
	90	ALL	304 SS*
Formaldehyde	50	50%	304 SS
	50-290	50%	304 SS*
Formic Acid (Anhydrous)	90	ALL	Cap. 20
Freon (F-11)	200	ALL	Monel
	200	ALL	316 SS*
Furfural	200		
	200	ALL	304 SS*
Gallic Acid	240	ALL	TFE

CORROSIVE AGENT	Deg C	CONC %	RECOMMENDED MATERIAL
	190	ALL	FEP
	200	ALL	316 SS*
Gasoline (Unleaded)	150	ALL	Hast. C
	20	ALL	446 SS
	170		Steel*
	200	ALL	316 SS*
Calcium Disulfite	90	ALL	TFE
	190	ALL	FEP
	170	ALL	316 SS*
Calcium Chlorate	240	ALL	TFE
	190	ALL	FEP
	90	ALL	316 SS*
Calcium Chloride(Saturate)	170	ALL	Hast. C
	90	ALL	Cap 20*
Gasoline (Refined)	240		TFE
	190		FEP
	90		Steel*
Glucose	30	ALL	Nickel
	190	ALL	316 SS*
Glue	30	ALL	Hast. B
	60	ALL	Steel*
Glycerine	130	ALL	304 SS
Iodine	250	ALL	Hast. C
	20	ALL	Nickel
Hydrogen Peroxide	90	90%	Hast. C
Hydrogen Sulfide (Dry)	70	ALL	316 SS
	290	ALL	316 SS
Hydrobromic Acid	90	50%	Titanium
	120	50%	Hast. B*
Hydrochloric Acid	60	38%	Hast. B
Hydrocyanic Acid	240	ALL	TFE
	190	ALL	FEP
	170	ALL	316 SS*
Hydrofluoric Acid	240	ALL	TFE
	190	ALL	FEP
	90	ALL	Hast. C*
Hydrogen Chloride (Gas, Dry)	290	ALL	Carp
Hydrogen Fluoride (Dry)	40	ALL	304 SS
	200	ALL	304 SS*
Kerosene	240	ALL	TFE
	190	ALL	FEP
	170		
Ketones	30	ALL	Hast. C
	130	ALL	316 SS*
Lactic Acid	150	ALL	Titanium
	120	ALL	Hast. B*
Lime (sulfur)	240	ALL	TFE
	190	ALL	FEP
	150	ALL	316 SS*
Linseed Oil	60	ALL	Carp. 20
	30	ALL	Steel*
Magnesium Chloride	140	ALL	Nickel
	90	50%	Carp. 20*
Magnesium Hydroxide	90	ALL	304 SS
Magnesium Sulfate	90	60%	Nickel
	170	ALL	316 SS*
Mercuric Chloride	140	ALL	Tantalum
	80	10%	Hast. C*
Mercury	290	ALL	304 SS
Methyl Chloride(Dry)	170	ALL	316 SS
Methylene Chloride	90	ALL	Carp. 20
Milk	90	304	SS 380
Naphtha	20	ALL	446 SS

CORROSIVE AGENT	Deg C	CONC %	RECOMMENDED MATERIAL
	120	ALL	304 SS
Natural Gas	240		TFE
	190		FEP
	40		Steel*
Nickel Chloride	90	80%	Hast. C 3040SS*
Nickel Sulfate	80	10%	Tantalum
	90	ALL	304 SS*
Nitric Acid	20	ALL	304 SS
	90	40%	304 SS
Nitrobenzene	140	ALL	Carp. 20
	170	ALL	316 SS*
Oleic Acid	140	ALL	316 SS
Oleum	50	40%	Hast. C
	120	ALL	316 SS*
Oxalic Acid	90	ALL	Tantalum
	90	ALL	Carp. 20*
Oxygen	270	ALL	Tantalum
	20	ALL	446 SS
	170	ALL	316 SS*
Palmitic Acid	240	ALL	TFE
	190	ALL	FEP
	200	ALL	304 SS*
Phenol (Carbolic Acid)	290	ALL	316 SS
Phosphoric Acid	90	50-85%	Hast. C
	40	50-85%	Carp. 20
Photographic Solutions	170	ALL	316 SS
Picric Acid	30	ALL	Titanium
	20	ALL	Aluminum
	200	ALL	316 SS*
Potassium Bromide	90	30%	Titanium
	90	30%	446 SS
Potassium Carbonate	90	50%	304 SS
Potassium Chlorate	170	30%	316 SS
Potassium Hydroxide	90	50%	Nickel
Potassium Nitrate	170	80%	Aluminum
	280	80%	446 SS*
Potassium Permanganate	20	20%	Hast. C
	170	20%	316 SS*
Potassium Sulfate	170	10%	316 SS
Propane	60	ALL	446 SS
	30	ALL	Brass
Pyrogallic Acid	30	ALL	Copper
	170	ALL	316 SS*
Salicylic Acid	120	ALL	Hast. C
	170	ALL	316 SS*
Sea Water (Stagnant)			Monel
Sea Water (Cavitation)	(20)		316 SS
Soap Solutions	20	ALL	446 SS
	50	ALL	Nickel*
Sodium Bicarbonate	170	20%	316 SS
Sodium Bisulfite	70	10%	316 SS
	90	10-40%	Carp. 20
Sodium Carbonate	90	30%	Carp. 20
	290	10-100%	Hast. B*
Sodium Chloride	30	30%	Nickel
Sodium Fluoride	70	ALL	Monel
	80	ALL	Carp. 20*
Sodium Hydroxide	100	70%	Monel
	70	ALL	316 SS*
Sodium Nitrate	170	60%	316 SS*
Sodium Nitrite	90	SAT	Titanium
	90	40%	304 SS*
Sodium Peroxide	20	10%	446 SS
Sulfur	290	ALL	304 SS
	70	ALL	Alloy 556
Sulfur Chloride (Dry)	30	ALL	Tantalum
	290	ALL	Nickel*
Sulfur Dioxide (Dry)	50	ALL	Steel
	290	ALL	316 SS*

CORROSIVE AGENT	Deg C	CONC %	RECOMMENDED MATERIAL
Sulfur Trioxide (Dry)	240	ALL	TFE
	190	ALL	FEB
	290	ALL	304 SS*
Sulfuric Acid	40	100	Carp. 20
	120	60%	Hast. B
Sulfurous Acid	70	ALL	Titanium
	180	ALL	Carp. 20
Steam (Law Pressure)			Inconel
			304 SS*
(Medium Pressure)			Nickel
			304 SS*
(High Pressure)			316 SS*
Tannic Acid	90	10	20% Titanium
	90	ALL	304 SS*
Tartaric Acid	200	ALL	304 SS
Titanium Tetrachloride	30	ALL	Carp.
	140	ALL	Titanium
Toulene (Toluol)	170	ALL	Steel
	90	ALL	304 SS
Trichloroacetic Acid	240	ALL	TFE
	190	ALL	FEP
	90	ALL	Hast. C*
Trichloroethylene	70	ALL	Inconel
Turpentine	90	ALL	304 SS
Whiskey and Wine		ALL	304 SS
Xylene (Xylol)	90	ALL	446 SS
Zinc Chloride	80	TO 70%	Titanium
	290	ALL	Hast. B
Zinc Sulfate	90	SAT	316 SS

EMITTANCE VALUES FOR POLISHED AND OXIDIZED METALS

WAVE LENGTH	0.6-1.1 µm		2-2.8 µm		5 µm				8 - 14 µm
MATERIAL	SMOOTH POLISH	SMOOTH OXIDIZED	SMOOTH POLISH	SMOOTH OXIDIZED	SMOOTH POLISH	SMOOTH OXIDIZED	SMOOTH POLISH	SMOOTH OXIDIZED	SMOOTH OXIDIZED
Alimel	0.32	0.90	0.25	0.90	0.10	0.90	0.10	0.90	
Aluminium	0.15	0.25	0.10	0.20	0.05	0.15	0.08	0.15	0.9*
Brass	0.20	0.70	0.10	0.70	0.05	0.70	0.07	0.70	
Carbon Steel	0.33	0.75	0.25	0.75	0.11	0.75	0.15	0.75	0.8
Chromel	0.33	0.90	0.25	0.90	0.10	0.90	0.15	0.90	0.9
Chromium	0.40	0.70	0.30	0.70	0.19	0.70	0.25	0.70	
Cobalt	0.33	0.75	0.25	0.75	0.15	0.75	0.20	0.75	
Copper	0.10	0.70	0.04	0.70	0.02	0.70	0.03	0.70	
Graphite (Smootgh)	0.80	-	0.80	-	0.80	-	0.80	-	0.8
Iron	0.33	0.70	0.25	0.70	0.09	0.70	0.15	0.70	0.8
Lead	0.25	0.70	0.15	0.70	0.08	0.70	0.10	0.70	
Manganese	0.45	0.90	0.30	0.90	0.20	0.90	0.22	0.90	
Molybdenum	0.38	-	0.28	-	0.18	-	0.15	-	-
Nichrome	0.36	0.90	0.26	0.90	0.17	0.90	0.22	0.90	0.9
Nickel	0.32	0.90	0.15	0.90	0.06	0.90	0.08	0.90	
Platinum	0.27	-	0.18	-	0.06	-	0.10	-	-
Silver	0.05	0.80	0.03	0.80	0.03	0.80	0.03	0.80	
Silicon	0.70	-	0.7	-	0.70	-	0.70	-	-
Stainless Steel	0.33	0.85	0.25	0.85	0.10	0.85	0.15	0.85	0.8
Tantalum	0.27	0.70	0.10	0.70	0.07	0.70	0.08	0.70	
Tin	0.35	0.60	0.22	0.60	0.18	0.60	0.18	0.60	
Tungusten	0.40	0.60	0.10	0.60	0.05	0.60	0.06	0.60	
Vanadium	0.36	0.75	0.29	0.75	0.18	0.75	0.25	0.75	
Zinc	0.20	0.50	0.07	0.50	0.03	0.50	0.15	0.50	
Zirconium	0.30	0.40	0.22	0.40	0.14	0.40	0.15	0.40	

*The values listed refer to flat polished specimens and to the oxides formed on these surfaces_ Roughening of these Surfaces raises the emittance values. A long narrow hole or crevice in any of the above produces a blackbody with e=1.0 **Electrolytically Anodized Not Oxidized

Temperature Conversion							
FROM °C to °F				FROM °F to °C			
°C	°F	°C	°F	°F	°C	°F	°C
-50	-58	1750	3182	-50	-45.56	1800	982.22
-40	-40	1800	3272	-40	-40	1850	1010
-30	-22	1850	3362	-30	-34.44	1900	1037.78
-20	-4	1900	3452	-20	-28.89	1950	1065.56
-10	14	1950	3542	-10	-23.33	2000	1093.33
-5	23	2000	3632	-5	-20.56	2050	1121.11
-2	28.4	2050	3722	-2	-18.56	2100	1148.89
-1	30.2	2100	3812	-1	-18.33	2150	1176.67
0	32			0	-17.78	2200	1204.44
5	41			5	-15	2250	1232.22
10	50			10	-12.22	2300	1260
20	68			20	-6.67	2350	1287.78
30	86			30	-1.11	2400	1315.56
40	104			40	4.44	2450	1343.33
50	122			50	10	2500	1371.11
100	212			100	37.78	2550	1398.89
150	302			150	65.56	2600	1426.67
200	392			200	93.33	2650	1454.44
250	482			250	121.11	2700	1482.22
300	572			300	148.89	2750	1510
350	662			350	176.67	2800	1537.78
400	752			400	204.44	2850	1565.56
450	842			450	232.22	2900	1593.33
500	932			500	260	2950	1621.11
550	1022			550	287.78	3000	1648.89
600	1112			600	315.56	3050	1676.67
650	1202			650	343.33	3100	1704.44
700	1292			700	371.11	3150	1732.22
750	1382			750	398.89	3200	1760
800	1472			800	426.67	3250	1778.78
850	1562			850	454.44	3300	1815.56
900	1652			900	482.22	3350	1843.33
950	1742			950	510	3400	1871.11
1000	1832			1000	537.78	3450	1898.89
1050	1922			1050	565.56	3500	1926.67
1100	2012			1100	593.33	3550	1954.44
1150	2102			1150	621.11	3600	1982.22
1200	2192			1200	648.89	3650	2010
1250	2282			1250	676.67	3700	2037.78
1300	2372			1300	704.44	3750	2065.56
1350	2462			1350	732.22	3800	2093.33
1400	2552			1400	760	3850	2121.11
1450	2642			1450	787.78	3900	2148.89
1500	2732			1500	815.56	3950	2176.67
1550	2842			1550	843.33	4000	2204.44
1600	2912			1600	871.11	4050	2232.22
1650	3002			1650	898.89	4100	2260
1700	3092			1700	926.67	4150	2287.78

°F = 1.8°C + 32, °C = (°F- 32) / 1/8

Conductor Size Equivalents (Diameter)

No	SWG		B & S(AWG)		No	SWG		B & S(AWG)	
	Inches	mm	Inches	mm		Inches	mm	Inches	mm
0	0.324	8.23	0.3249	8.25	26	0.018	0.457	0.0159	0.404
1	0.300	7.62	0.2893	7.35	27	0.0164	0.417	0.0142	0.361
2	0.276	7.01	0.2576	6.54	28	0.0148	0.376	0.0126	0.320
3	0.256	6.40	0.2294	5.83	29	0.0136	0.345	0.0113	0.287
4	0.232	5.89	0.2043	5.19	30	0.0124	0.315	0.0100	0.254
5	0.212	5.38	0.1819	4.62	31	0.0116	0.295	0.0089	0.226
6	0.192	4.88	0.1620	4.11	32	0.0108	0.274	0.0080	0.203
7	0.176	4.47	0.1443	3.67	33	0.0100	0.254	0.0071	0.180
8	0.160	4.06	0.1285	3.26	34	0.0092	0.234	0.0063	0.160
9	0.144	3.66	0.1144	2.91	35	0.0084	0.213	0.0056	0.142
10	0.128	3.25	0.1019	2.59	36	0.0076	0.193	0.0050	0.127
11	0.116	2.95	0.0907	2.3	37	0.0068	0.173	0.0045	0.114
12	0.104	2.64	0.0808	2.05	38	0.006	0.152	0.0040	0.102
13	0.092	2.34	0.0720	1.83	39	0.0052	0.132	0.0035	0.089
14	0.080	2.03	0.0641	1.63	40	0.0048	0.122	0.0031	0.079
15	0.072	1.83	0.0571	1.45	41	0.0044	0.112	0.0028	0.071
16	0.064	1.63	0.0508	1.29	42	0.0040	0.102	0.0025	0.064
17	0.056	1.42	0.0453	1.15	43	0.0036	0.091	0.0022	0.056
18	0.048	1.22	0.0403	1.02	44	0.0032	0.081	0.0020	0.051
19	0.040	1.02	0.0359	0.912	45	0.0028	0.071	0.0018	0.046
20	0.036	0.914	0.0320	0.813	46	0.0024	0.061		
21	0.32	0.813	0.0285	0.724	47	0.0020	0.051		
22	0.028	0.711	0.0253	0.643	48	0.0016	0.041		
23	0.024	0.610	0.0226	0.574	49	0.0012	0.030		
24	0.022	0.559	0.0201	0.511	50	0.0010	0.025		
24	0.020	0.508	0.0179	0.455					

SWG = (BRITISH) STANDARD WIRE GAUGE
B&S = BROWN AND SHARPE
AWG = AMERICAN WIRE GAUGE

Loop Resistance, Ohms per Double meter Approximate (Sizes in mm)

Code	1/0.2	1/0.315	1/0.508	7/0.2	13/0.2	14/0.2	23/0.2
E	38.1	15.4	5.9	5.3	2.9	2.7	1.6
J	19.3	7.8	3.0	2.7	1.5	1.4	0.8
K	31.8	12.8	4.9	4.5	2.4	2.2	1.4
N	44.2	17.7	6.8	6.2	3.4	3.2	1.9
T	16.2	6.5	2.5	2.3	1.2	1.1	0.7
U	1.4	0.6	0.2	0.2	0.1	0.1	0.1
VX	16.2	6.5	2.5	2.3	1.2	1.1	0.7

Conductor Cross Sectional Areas

Metric	mm^2	SWG	AWG	Single Strand	
				Dia. Inches	Dia. mm
1/0.315	0.078	30	-	0.0124	0.31
1/0.2	0.032	-	32	0.0080	0.20
1/0.508	0.203	25	-	0.0200	0.51
7/0.2	0.219	-	-	0.0206	0.52
1/0.711	0.400	22	-	0.0280	0.71
14/0.2	0.412	-	21	0.0285	0.72
32/0.2	1.00	-	-	0.0445	1.13
1/1.29	1.30	-		0.5040	1.28

Insulated Wire Sizes (Subject to Variation)

Sizes in mm

INSULATION	Wire Size (mm)	Each Insulated Conductor (mm)	Overall Sheath (mm)
PVC			
Flat Pair	1/0.508	-	1.4 x 2.7
Flat Pair	7/0.2	1.7	3.4 x 4.8
Flat Pair	13/0.2	1.9	3.4 x 5.1
Flat Pair	23/0.2	2.0	3.5 x 5.5
PTFE			
Twisted Pair	1/0.2	0.6	
Twisted Pair	1/0.315	0.7	
Twisted Pair	1/0.508	0.8	
Flat Pair	1/0.315	0.6	1.3 x 1.9
Flat Pair	7/0.2	0.9	5.5 x 2.4
GLASS FIBRE			
Flat Pair	1/0.2	0.5	1.0 x 1.4
Flat Pair	1/0.315	0.7	1.1 x 1.7
Flat Pair	1/0.508	0.8	1.3 x 2.0
Flat Pair	7/0.2	0.8	1.1 x 1.9
Flat Pair	14/0.2	1.0	1.3 x 2.2
GLASS FIBRE & S.S. OVERBRAID	7/0.2	0.9	1.6 x 2.4

Nominal Analysis of Metal Protection Tubes

AISI ASTM	EN DIN	C% Max	Mn% Max	Si% Max	S% Max	P% Max	Cr% Max	Ni% Max	Others %
202	-	0.15	7.5-10	1.00	0.030	0.060	17.00-19.00	4.00-6.00	-
303	1.4305	0.15	2.00	1.00	0.15 Min	0.20	17.00-19.00	8.00-10.00	Cu:1% max
304	1.4301	0.08	2.00	1.00	0.030	0.045	18.00-20.00	8.00-11.00	-
304L	1.4306	0.03	2.00	1.00	0.030	0.045	18.00-20.00	8.00-12.00	-
310	1.4841	0.25	2.00	1.50	0.030	0.045	24.00-26.00	19.00-22.00	-
316	1.4401	0.08	2.00	1.00	0.030	0.045	16.00-18.00	10.00-14.00	M0: 2.00-3.00
316L	1.4404	0.03	2.00	1.00	0.030	0.045	16.00-18.00	10.00-14.00	Mo: 2.00-3.00
316Ti	1.4571	0.08	2.00	1.00	0.030	0.045	16.00-18.00	10.00-14.00	Ti : Min (5xC%), Mo: 2.00-3.00
321	1.4541	0.08	2.00	1.00	0.030	0.045	17.00-19.00	9.00-12.00	Ti : Min (5xC%)
347 SS	-	0.80	2.00	1.00	0.030	0.045	17.00-19.00	9.00-13.00	Nb : 10x C%
446 SS	-	0.20	1.50	1.00	0.030	0.040	23.00-27.00	-	N: 0.25
253 MA	-	-	0.6	1.7	-	-	21	11	Ce: 0.04 N: 0.17
Kanthal 1	-	-	-	-	-	-	22	-	Al: 5.8
Inconel 600	-	0.15	1.00	0.50	0.015	0.030	14.00-17.00	72.00	Trace Co <Cu:0.50
Inconel 625	-	0.10	0.50	0.50	0.015	0.030	21.5	Bal.	Mo9 Nb+ Ta: 3.7
Inconel 825	-	0.05	1.0	0.50	0.03	0.030	19.5-23.5	38-46	Al:<0.2, Ti:0.6-1.2, Mo:2.5-3.5
Inconel 800	-	0.10	1.50	1.00	0.015	0.030	19.00-23.00	30.00 35.00	Trace Cu, Trace Co, Al, Ti
UMCo-50	-	0.05-0.15	0.30-1.00	1.00	0.020	0.020	26.00-30.00	3.00	Co 50 Trace Mo
Hastelloy B	-	0.05	1.00	1.00	0.03	0.04	-	Bal.	Fe: 5.0, Mo: 28, Co: 2.5, V:0.6
Hastelloy C-276	-	0.002	1.00	0.08	0.03	0.04	14.5-16.5	Bal.	Mo: 15-17 Trace W, Co, V
Hastelloy X	-	0.05	1.00	1.00	0.030	0.040	20.50-23.00	Bal.	Mo: 8-10.00, W0.6, Co: 1.5, trace B
Monel 400	-	Monel 400	Monel 400	Monel 400	Monel 400	Monel 400	Monel 400	Monel 400	Monel 400

ANSI B16.5 FLANGE DETAILS

PIPE		FLANGE							
NOMINAL SIZE	O.D.	ib/sq.in	O.D.	R.F.	THICKNES S	RFT	NO. OF HOLES	HOLE DIA	PCD
INCH	mm		mm	mm	mm	mm		mm	mm
1/2"	21.3	150	88.9	35.1	11.2	1.6	4	15.7	60.5
3/4”	26.7	150	98.6	42.9	12.7	1.6	4	15.7	69.9
1.0”	33.4	150	108.0	50.8	14.2	1.6	4	15.7	79.2
1-1/4”	42.2	150	112.3	63.5	15.2	1.6	4	15.7	88.9
1-1/2”	48.3	150	127.0	73.2	17.5	1.6	4	15.7	98.6
2”	60.3	150	152.4	91.9	19.6	1.6	4	19.1	120.2
2-1/2”	73	150	177.8	104.6	22.4	1.6	4	19.1	139.7
3.0”	88.9	150	190.5	127.0	23.9	1.6	4	19.1	152.4
1/2"	21.3	300	95.2	35.0	14.2	1.6	4	15.7	60.9
3/4”	26.7	300	117.3	42.9	15.9	1.6	4	19.1	82.6
1.0”	33.4	300	124.0	50.8	17.5	1.6	4	19.1	88.9
1-1/4”	42.2	300	133.3	63.5	19	1.6	4	19.1	98.6
1-1/2”	48.3	300	155.4	73.2	20.6	1.6	4	22.3	114.0
2”	60.3	300	165.1	91.9	22.3	1.6	4	19.0	127.0
2-1/2”	73	300	190.5	104.6	25.4	1.6	4	22.3	149.4
3.0”	88.9	300	209.6	127.0	28.4	1.6	4	22.3	168.4
1/2"	21.3	400/600	95.2	35.0	20.6	6.4	4	15.7	66.5
3/4”	26.7	400/600	117.3	42.9	22.0	6.4	4	19.1	82.6
1.0”	33.4	400/600	124.0	50.8	23.9	6.4	4	19.1	88.9
1-1/4”	42.2	400/600	133.3	63.5	27.0	6.4	4	19.1	98.6
1-1/2”	48.3	400/600	155.4	73.2	28.8	6.4	4	22.4	114.3
2”	60.3	400/600	165.1	91.9	30.8	6.4	8	19.1	127.0
2-1/2”	73	400/600	190.5	104.6	34.8	6.4	8	22.4	149.4
3.0”	88.9	400/600	209.6	122.0	38.8	6.4	8	22.4	168.1

TOLERANCE CHART (FLANGE)

DIMENSION OPF FLANGE	TOLERANCE
O.D.	±0.6 mm
RFT - 1.6 mm	±0.8 mm
- 6.4 mm	±0.4 mm
PCD	±1.6 mm
4 HOLE DIA	±0.8 mm
THICKNESS	±3.2 mm

ANSI B16.5 FLANGE DETAILS

PIPE		FLANGE							
NOMINAL SIZE	O.D.	ib/sq.in	O.D.	R.F.	THICKNES S	RFT	NO. OF HOLES	HOLE DIA	PCD
INCH	mm		mm	mm	mm	mm		mm	mm
1/2"	-	900/1500	120.65	35.1	22.35	6.4	4	22.35	82.55
3/4”	-	900/1500	130.04	42.9	25.4	6.4	4	22.35	88.9
1.0”	-	900/1500	149.35	50.8	28.44	6.4	4	25.4	101.6
1-1/4”	-	900/1500	158.75	63.5	28.44	6.4	4	25.4	112.25
1-1/2”	-	900/1500	177.8	73.15	31.75	6.4	4	28.44	124
2”	-	900/1500	215.9	91.95	38.1	6.4	8	25.4	165.1
2-1/2”	-	900/1500	244.34	104.64	41.14	6.4	8	28.44	190.5
3.0”	-	900/1500	266.7	127	47.7	6.4	8	31.75	203.2
1/2"	-	2500	133.35	35	30.22	6.4	4	22.35	88.9
3/4”	-	2500	139.7	42.92	31.75	6.4	4	22.35	95.25
1.0”	-	2500	158.75	50.8	35.05	6.4	4	25.4	108
1-1/4”	-	2500	184.15	63.5	38.1	6.4	4	28.44	130.04
1-1/2”	-	2500	203.2	73.15	44.45	6.4	4	31.75	146.05
2”	-	2500	235	91.94	50.8	6.4	8	28.44	171.45
2-1/2”	-	2500	266.7	104.64	57.15	1.6	8	31.75	196.85
3.0”	-	2500	304.8	127	66.54	1.6	8	35.05	228.6

B.S.P. THREADS DETAILS

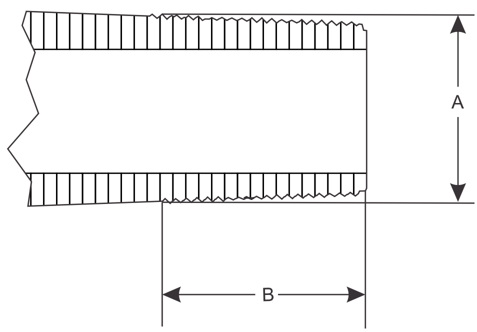
NOMINAL SIZE	PITCH	TPI	INTERNAL THREADS					EXTERRNAL THREADS						THREAD DEPTH	RADIUS
			MAJOR DIA(D)	PITCH DIA(D2)		MINOR DIA(D2)		MAJOR DIA(d)		PITCH DIA(d2)		MINOR DIA(d1)			
(INCHES)	(P)		MIN.	MIN.	MAX.	MIN.	MAX.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	(h)	r
(1/16)	0.907	28	7.723	7.142	7.269	6.561	6.843	7.723	7.509	7.142	7.033	6.561	6.427	0.581	0.125
(1/8)	0.907	28	9.728	9.728	9.254	8.566	8.848	9.728	9.514	9.147	9.04	8.566	8.432	0.581	0.125
(1/4)	1.337	19	13.157	12.301	12.426	11.445	11.89	13.157	12.905	12.301	12.126	11.445	11.289	0.856	0.184
(3/8)	1.337	19	16.662	15.806	15.931	14.95	15.395	16.662	16.412	15.806	15.681	14.95	14.794	0.856	0.184
(½)	1.814	14	20.995	19.793	19.935	18.631	19.172	20.955	20.671	19.793	19.651	18.631	18.453	1.162	0.249
(5/8)	1.814	14	22.911	21.749	21.891	22.587	21.128	22.911	22.627	21.749	21.607	20.587	20.409	1.162	0.249
(3/4)	1.814	14	26.441	25.279	25.421	24.117	24.658	26.441	26.157	25.279	25.137	24.117	23.939	1.162	0.249
(7/8)	1.814	14	30.201	29.039	29.181	27.877	28.418	30.201	29.912	29.039	28.897	27.877	27.699	1.162	0.249
(1/1)	2.309	11	33.249	31.77	31.95	30.291	30.931	33.249	32.889	31.77	31.59	30.294	30.066	1.479	0.317
(1-1/8)	2.309	11	37.887	36.418	36.598	34.939	35.579	37.897	37.537	36.418	36.238	34.939	34.714	1.479	0.317
(1-1/4)	2.309	11	41.91	40.431	40.611	38.952	39.592	41.91	41.93	40.431	40.251	38.952	38.727	1.479	0.317
(1-1/2)	2.309	11	47.8	46.314	46.504	44.845	45.485	47.803	47.443	46.324	46.144	44.845	44.62	1.479	0.317
(1-3/4)	2.309	11	53.746	52.267	52.447	50.788	51.428	53.745	53.386	52.267	52.087	50.788	50.563	1.479	0.317
(2/1)	2.309	11	59.614	58.135	58.315	56.626	57.296	59.614	59.254	58.135	57.955	56.696	56.431	1.479	0.317

WEIGHT AND THICKNESS OF S.S. GAUGE PIPE

Diameter D Nominal Inches	Outside Diameter mm	Schedule 5 S Thickness T mm	Wt. kg/m	Schedule10 S Thickness T mm	Wt. kg/m	Schedule40 S Thickness T mm	Wt. kg/m	Schedule80 S Thickness T mm	Wt. kg/m
1/4	13.720	1.240	0.390	1.650	0.498	2.240	0.643	3.020	0.807
3/8	17.150	1.240	0.492	1.650	0.638	2.310	0.855	3.200	1.113
1/2	21.340	1.650	0.812	2.110	1.013	2.770	1.285	3.730	1.640
3/4	26.670	1.650	1.035	2.110	1.300	2.870	1.712	3.910	2.230
1	33.400	1.650	1.311	2.770	2.123	3.380	2.540	4.550	3.285
1 1/4	42.160	1.650	1.675	2.770	2.734	3.560	3.443	4.850	4.534
1 1/2	48.260	1.650	1.926	2.770	3.160	3.680	4.110	5.080	5.496
2	60.330	1.650	2.422	2.770	3.990	3.910	5.520	5.540	7.593
2 1/2	73.030	2.110	3.744	3.050	5.340	5.160	8.760	7.010	11.580
3	88.900	2.110	4.584	3.050	6.550	5.490	11.460	7.620	15.550
3 1/2	101.600	2.110	5.254	3.050	7.520	5.740	13.770	8.080	18.910
4	114.300	3.050	8.490	6.020	16.320	8.560	22.660	13.490	34.040

National Pipe Taper Thread Dimensions

NPT SIZE	THREADS PER INCH	DIM "A" (IN)	DIM "B" (IN)
1/16	27	0.312	0.261
1/8	27	0.405	0.264
1/4	18	0.540	0.402
3/8	18	0.675	0.408
½	14	0.840	0.534
3/4	14	1.050	0.546
1	11 1/2	1.315	0.683
1 1/4	11 1/2	1.660	0.707



GLOSSARY

1. Abbreviations and Acronyms for Standards & Standards bodies

ANSI	American National Standard Institute
ASTM	American Society for Testing and Material
BS	British Standard
DIN	Deutche Industial Norms
IEC	International Electrotechnical Commission
IPTS-68	International Practical Temperature Scale of 1968
ITS-90	International Temperature Scale 1990
IS	Indian Standard

2. Calibration

Calibration	Checking/Measuring Accuracy against an External Reference/Standard
Calibrator	Device used for or in calibration
Drift	Change in the value of a parameter due to operational influence (e.g. temperature variation/ageing)
Dry Block Calibrator	A thermal device which does not use a fluid medium as a temperature source
Fixed Points(Temperature)	Temperature defined by physical laws, Change of state of pure material
Fixed Point Cell	A device used to provide a fixed point temperature
Primary Standards	Those derived from the best available equipment. Pertaining to establishing the International Temperature Scale
Reference Probe	Certified Probe used as a comparison standard
Secondary Standard	Traceable to primary standard
Standard Resistance Thermometer	A laboratory standard probe for the highest possible accuracy of measurement
Stirred Liquid Bath	A controlled thermal reference which uses a stirred liquid medium
Temperature Calibration Point	A temperature value at which calibration is performed by comparison or direct techniques
Thermal Calibration	Calibration using a temperature source (I.e. not electrical)
Thermal Reference	Controller Temperature Source
Tolerance	Stated Uncertainties
Triple Point of Water	A thermodynamic state (of water) in which the gas, Liquid and solid phases all occur in equilibrium. Value 0.01°C
Uncertainties	Possible Inaccuracies

3. Control

Auto-manual	Selection of closed loop (Automatic) or open loop (manual) regulation
Auto-tune	Automatic selection of the control terms, usually P, I & D
Calibration	Checking/Measuring accuracy against an external reference or standard.
Closed Loop	Automatic control via feedback
Cold Junction	Built in, automatic cementation for ambient temperature
Compensation(Automatic)	Variations when using a thermocouple sensor
Control Output	The means of controlling energy regulation in the process
D	Abbreviation of Derivative
Dead-band	On-Off hysteres to prevent excessively rapid power switching
Derivative Time Constant	A measure of derivative term sensitivity
Hysteresis	Dead-band defined in on-off switching
I	Abbreviation of Integral
Integral Time	Summation period for offset computation
Offset	Difference between set-point and resultant control point
On-Off	Power regulation by simple on-off switching (e.g. thermostat)
Open Loop	System not utilizing feedback (I.e. not capable of automatic control.)
Output	Control signal or communication data
Overshoot	The amount by which the process temperature exceeds set- point on start up
P	Abbreviation of propotional

Process	The system being monitored or controlled
Process Variable	The parameter monitored or controlled
Proportional Band	The control band within power is regulated between 0 and 100% usually expressed
Set-Point	Desired process temperature set by the operator
Start-Up	Dynamic state of the process after switching on
Thermal Mass	Heat storage effect in the process

4. Instrumentation General

Closed Loop	Facility for automatic control by means of temperature feedback from the process to the Instrument
Control	Regulation of process energy to achieve a desired temperature
Control	Regulation of process energy to achieve a desired temperature
Data Acquisition	Gathering data from a process, Usually electronic, Usually automatic
Indication	Analogue or digital readout of data
Input	The connector point for a sensor or defines type of sensor
Isolation	Electrically isolation condition
Linearisation	Matching the transfer characteristic of the sensor if non-linear (strictly de-linearisation)
Logging	Recording data
Non-linear	Not a straight line transfer characteristics
Open loop	System not utilizing feedback
Process	The system being monitored
Signal Conditioning	Changing the electrical characteristics of a sensor signal
Stability	The ability of an instrument to maintain a constant output with the application of a constant input
Temperature Coefficient Transmitter	An Amount by which a parameter varies due to temperature Instrumentation. Usually converts to 4-20mA.

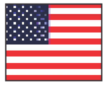
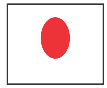
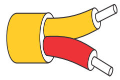
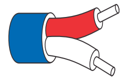
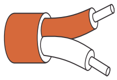
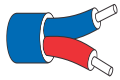
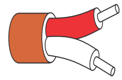
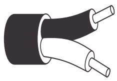
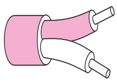
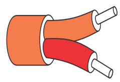
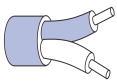
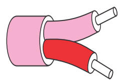
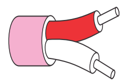
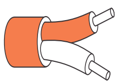
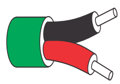
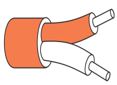
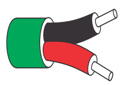
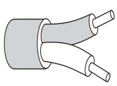
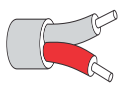
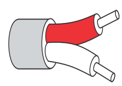
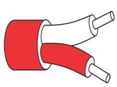
5. Thermometerey - General

Absolute zero	The lowest possible temperature of a body due to absence of molecular motion. Stated as 0 Kelvin, equivalent to -273.15°C
Alpha α	The temperature coefficient of resistance of a sensing resistor. Expressed as Ω/°C.
Alumina	Aluminium Oxide (a refectory material)
Base Metal Thermocouple	Thermocouple utilizing base metal
Boiling Point	The equilibrium temperature between a liquid and its vapour
Ceramic	Refractory insulating material
Coefficient (α,β,γ)	Used in the Pt100 Characteristics polynomial; they define the temperature resistance relationship.
Cold Junction	Reference junction of a thermocouple
Cold Junction	Compensation for thermocouple reference junction
Compensation (CJC)	Temperature Variations
Colour Codes	Means of cable and sensor type identification; applied internationally according to appropriate standard
Compensating Cable	Used for connecting thermocouple to instruments; the conductor use low cost materials which have a similar ambient thermal emf relationship to that of the thermo element but at lower cost
Compression Fitting	Type of threaded fitting which compresses on to the probe sheath to provided a pressure tight coupling
Cryogenic	A term for very low temperatures, usually associated with liquified gases (-180°C)
Drift	Change in the value of a parameter due to operational influence (e.g. temperature variation/againig)
EMF	Electromotive force (sometimes referred to as thermo-voltage).
Excitation Current	Current supplied to an appropriate sensor or transducer to provide excitations
Exposed junction	A thermo junction not protected by sheath material. Used when fast thermal response is required

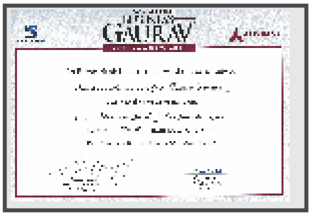
Extension Cable	Thermocouple connecting cable which uses conductors in true thermocouple alloy
Fabricated	Made from component part e.g. thermocouple assembly made from tubing, wire and insulating material as opposed to one made using mineral insulated cable
Fitting	Items used to secure probes into machinery e.g. compression gland threaded bushes, bayonet fittings
Fixed Points (Temperature)	Temperature defined by physical laws, change of state of pure material
Flange	Form of disc through which probe is installed into a process
Freezing Point	The fixed temperature point of a material which occurs during the transition from a liquid to solid state. Also known as melting point for pure materials
Fundamental Intervals	Thermometer resistance change over the range to 0 to 100°C
Grounded Hot Junction	Thermocouple configuration in which the thermo element is electrically common to the sheath
Hot Junction	Measuring junction of thermocouple
Ice Point	0°C
Immersion	Placing of probe into the process medium (I.e. immersion into some medium)
Insert	Replaceable probe assembly located inside outer sheath
Insulation Resistance	Value of resistance measuring between the sensor wire and sheath
Interchangeability	Describes how closely a sensor adheres to its defining equation
Isothermal	Equal temperature
Lagging Extension	Probe or pocket extension to allow for thickness of pipe or wall lagging
Leg	Common term for one thermoelement wire in a thermocouple circuit
Linearity	A deviation in response from straight the value of sensor
Loop Resistance	the total resistance of thermocouple circuit
Measuring Junction	Thermoelement measuring junction (Hot junction)
Melting Point	The temperature at which a substance convert from the solid to liquid phase. This is same as the freezing point for pure material
Metallic	Pertaining to presence of metal in sheath material as opposed to non-metallic
MI	Abbreviation for mineral insulated as used in sensor cable
Mineral Insulated	Type of cable construction used in thermometry. Conductors are insulated from sheath by compressed refractory oxide powder
Nobel Metal	Rare metal, usually platinum/Rhodium alloys
Noise	Unwanted electrical interference picked up on a single cable
NTC	Negative temperature coefficient (of resistance)
Parallel pair	Wire construction where two single conductor are laid parallel
Platinum resistance Thermometer	Platinum temperature sensor whose resistance varies with temperature
Polarity	Determines the direction of current flow its operating environment
Protection Tube	A tube (Sheath) which protect a sensor from its operating enviroment
PTC	Positive temperature coefficient (of resistance)
Rare Metal Thermocouple	Thermocouple made of rare metal thermoelement
Reference Junction	Of the thermocouple, usually referred to the ice point
Resistance thermometer	Temperature sensor, usually platinum, whose resistance varies with temperature
Response Time	A measure of thermal sensitivity applied to sensors. The time required for a sensor to reach 63% of the step change temperature under particular conditions
R0	The value of thermometer resistance temperature sensors at 0°C
RTD	Abbreviation for resistance temperature detector
Self-Heating	Heating effect due to current flow in the sensing resistance thermometer
Sensing Resistor	The sensing element of a resistance thermometer
Stability	The ability of a sensor to maintain a consistent output with the application of a constant input
Stem sensing	Sensing over a finite length as opposed to just the tip
Tails	Connecting wires emanating from the sensor
Thermal conductivity	The ability of a material to conduct heat
Thermal Gradient	The distribution of different temperature in and across an object
Thermal Mass	Heat storage effect in the process
Thermistor	A form resistance thermometer, usually a NTC type
Thermocouple type	Defines the of thermoelement e.g. J, K, T, N, R, S, B etc.

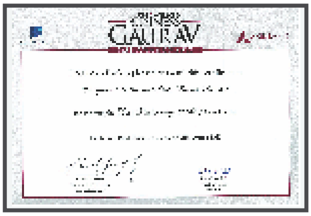
Thermoelectric	Electrical activity resulting from the generation of thermovoltage
Thermoelement	The two dissimilar conductor and their junction forming a thermocouple
Thermojunction	The junction formed between the dissimilar conductor of thermocouple. Usually describes the measuring junction.
Thermowell	Used to protect sensor probes against aggressive media. Effectively a pocket or well into whichthe probe is inserted
The Film	Sensing resistor in thin form (also flat film)
Tip Sensing	Temperature sensing at the tip of a probe only as opposed to along its length
Transducer	A device which converts energy from one form into another. Transducer often describes a sensor
Transfer Function	Input/Output characteristic of a device
Transmitter	A device for amplifying a sensor signal in order to permit its transmission to remote instrumentation. Usually converts to 4-20mA
Twisted Pair	Two insulated conductor twisted wires in thermocouple circuit minimise noise pick-up
Wheatstone bridge	Resistance bridge for precision measurement of Pt-100 sensing resistor
Wirewound	Sensing resistor in wirewound construction.

COLOR CODE OF COMPENSATING CABLES & THERMOCOUPLES

THERMOCOUPLE CONDUCTOR COMBINATION TYPE	INTERNATIONAL COLOUR CODE TO IEC 5843:1989	AMERICAN TO ANSI/MC96.1 	JAPANESE TO JIS C 1610-1981 
K	 + –	 + –	 + –
T	 + –	 + –	 + –
J	 + –	 + –	 + –
N	 + –	 + –	
E	 + –	 + –	 + –
R	 + –	 + –	 + –
S	 + –	 + –	 + –
B	 + –	 + –	 + –
C	 + –		

CERTIFICATES

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