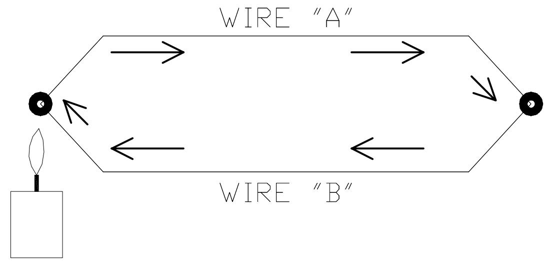
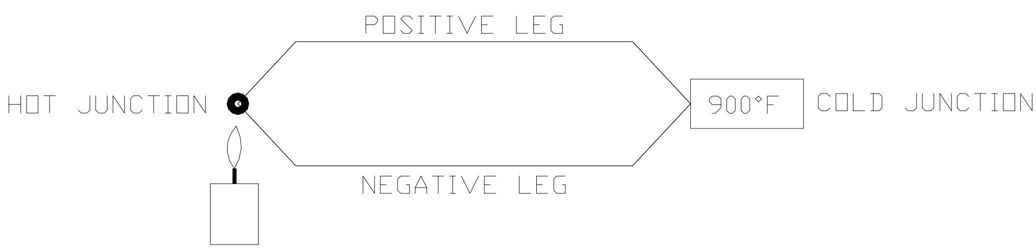
THERMOCOUPLE THEORY

WHAT'S A THERMOCOUPLE?

A thermocouple circuit is formed when two dissimilar metals are joined at both ends and there is a difference in temperature between the two ends. This difference in temperature creates a small current and is called the Seebeck effect after Thomas Seebeck who discovered this phenomenon in 1821.

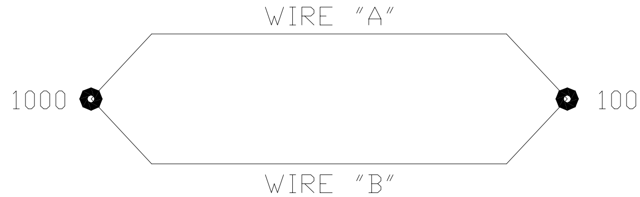


When there is a difference in temperature between the two ends of this circuit, a small voltage is formed within the circuit. This voltage or EMF (electro motive force) is usually measured in the 1/1000th of a volt (millivolt). Most people's body produces more voltage than that! The higher the difference in temperature, the higher the voltage. If the right pairs of materials are used, these thermocouple circuits can be used to measure temperature.



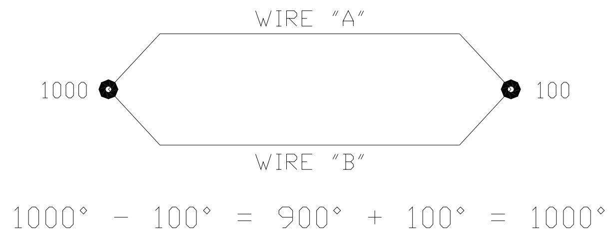
The junction that is put into the process in which temperature is being measured is called the HOT JUNCTION. The other junction which is at the last point of thermocouple material and which is almost always at some kind of measuring instrument, is called the COLD JUNCTION.

COLD JUNCTION COMPENSATION

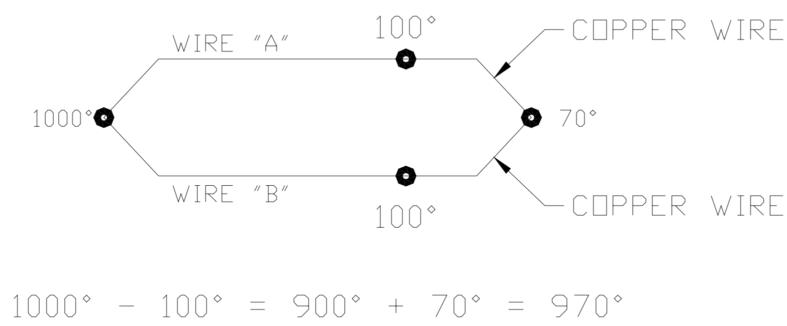


In the above example, one end of the thermocouple is @ 1000° and the other end is @ 100° so the difference is 900°. If we wanted to measure the temperature in a furnace, we could use a thermocouple to do so. If the above example were used, the temperature

inside the furnace is 1000° and the temperature outside is 100°, the thermocouple would indicate a difference in temperature between the inside and outside of 900°.
The only problem with the example above is that we want to know the temperature inside the furnace, not the difference between the outside and the inside. To do this with a thermocouple, we need to apply "Cold Junction Compensation". To apply this cold junction compensation, all we need to know is the temperature of the cold junction.



The measuring instrument normally does this cold junction compensation. The instrument measures the temperature at the point where the thermocouple attaches and adds that temperature back in to the equation as per the above example. The instrument then displays the result of this equation.
It is important to maintain thermocouple material throughout the circuit as in the case of a sensor that is located some distance from the measuring instrument. Specially coded extension wire is normally used.



In the above example, thermocouple extension wire was not used in the circuit and so an error has occurred due to incorrect cold junction compensation.

THERMOCOUPLE REFERENCE TABLES

Tables have been established worldwide that show temperature vs. millivolt output figures for the various accepted thermocouple combinations or "types".
These reference tables are all based on a reference or cold junction temperature of 32°F (0°C), which is the freezing point of pure water. All manufacturers follow these reference tables, which are published in ASTM document E-230.

THERMOCOUPLE TYPES

There are several different recognized thermocouple types available. Each type has different useful temperature ranges as well as different recommended applications. ASTM, which is recognized in the United States as the authority for temperature measurement, has established guidelines for the different thermocouple types. These guidelines cover composition, color codes, and manufacturing specifications.

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 (nickel/10% chromium) and a negative leg of constantan (nickel/45% copper). The temperature range for this thermocouple is –330 to 1600°F (-200 to 900°C). 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 sulfurous, vacuum or low oxygen atmospheres.
The color code for type E is purple for positive and red for negative.

Type J – Type J thermocouples have an iron positive leg and a constantan negative leg. Type J thermocouples have a useful temperature range of 32 to 1400°F (0 to 750°C) 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 used when choosing this type for use in oxidizing environments above 1000°F.
The color code for type J is white for positive and red for negative.

Type K – The type K thermocouple has a Chromel positive leg and an Alumel (nickel/ 5% aluminum and silicon) negative leg. The temperature range for type K alloys is –328 to 2282°F (-200 to 1250°C). 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 1000°F but vacuum and low oxygen conditions should be avoided.

Type N – Type N thermocouples are made with a Nicrosil (nickel – 14% chromium – 1.5 % silicon) positive leg and a Nisil (nickel – 4.5% silicon - .1% magnesium) negative leg. The temperature range for Type N is –450 to 2372°F (-270 to 1300°C) and the color code is orange for positive and red for negative. 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 –328 – 662°F (-200 to 350°C) and the color code is blue for positive and red for negative. Type T sensors can be used in oxidizing (below 700°F), reducing or inert applications.

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 are for use 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 32 – 2642°F (0 to 1450°C) and the color code is black for positive and red for negative.

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 32 – 2642°F (0 to 1450°C) and the color code is black for positive and red for negative.

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 r is 32 – 3092°F (0 to 1700°C) and the color code is gray for positive and red for negative.

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 500°F. 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 32 – 4208°F (0 – 2320°C). The color code for this type is white with red tracer for positive leg and red for the negative leg.

THERMOCOUPLE THEORY

LIMITS OF ERROR

Accuracy of temperature sensors is referred to as limits of error and apply only to brand new, un-used temperature sensors. Once a sensor is exposed to elevated temperatures, there is no guaranteed accuracy. All manufacturers adhere to these limits, which are establish by ASTM and are covered under their publication ASTM E –230. The Limits of Error tables appear in the SensorTec catalog as well as many competing manufactures catalogs.

TIDBITS ABOUT THERMOCOUPLES

- According to ASTM color code guidelines, which apply to most North American sensor manufacturers, the Red leg is always negative.
- 2 types of thermocouples (types J and K) have one leg, which is magnetic. With these 2 types, you can use a magnet to determine polarity.
- The hot junction of a thermocouple can be made by any means possible as long as there is good, constant contact between the two wires.
- Special limits of error thermocouple sensors do not have to have special limits of error extension wire.
- Non-thermocouple materials can be used in thermocouple circuits under the right conditions. Non-thermocouple connectors, terminals and slices can be used as long as there is no temperature gradient present at the areas where these items are used.
- Extension wire does not have to be a large gauge to work in an application where the sensor is placed a long way from the measuring instrument. Most modern temperature monitoring instruments are current based so lead wire resistance is not critical.
- It is possible to get an average temperature reading using multiple thermocouples as long as the sensors are wired in parallel and the resistance of these different sensors is the same.