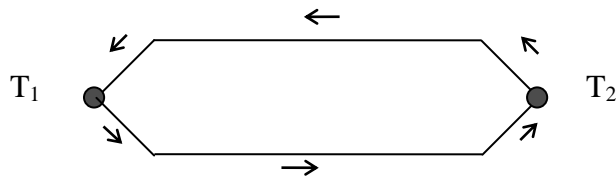


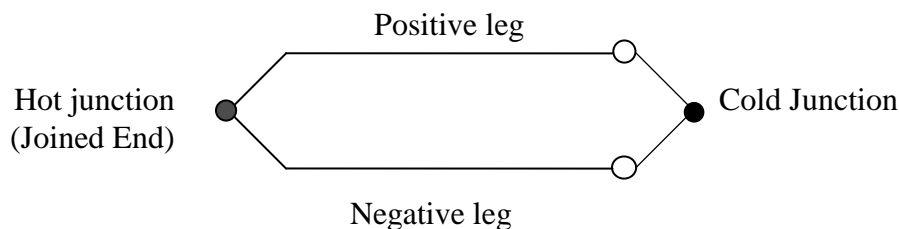
THERMOCOUPLE THEORY

WHAT IS A THERMOCOUPLE?

- ❖ In 1821, Thomas Seebeck discovered if metals of two different materials were joined at both ends and one end was at a different temperature than the other, a current was created. This phenomenon is known as the Seebeck effect and is the basis for all thermocouples.



- ❖ A thermocouple is a type of temperature sensor, which is made by joining two dissimilar metals at one end. The joined end is referred to as the HOT JUNCTION. The other end of these dissimilar metals is referred to as the COLD END or COLD JUNCTION. The cold junction is actually formed at the last point of thermocouple material



- ❖ Certain combinations of metals must be used to make up the thermocouple pairs.
- ❖ If there is a difference in temperature between the hot junction and cold junction, a small voltage is created. This voltage is referred to as an EMF (electro-motive force) and can be measured and in turn used to indicate temperature.
- ❖ The voltage created by a thermocouple is extremely small and is measured in terms of millivolts (one millivolt is equal to one thousandth of a volt). In fact, the human body creates a larger millivolt signal than a thermocouple.
- ❖ To establish a means to measure temperature with thermocouples, a standard scale of millivolt outputs was established. This scale was established using 32 deg. F (0°C) as the standard cold junction temperature (32 deg. F (0°C) = 0 millivolts output).

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COLD JUNCTION COMPENSATION

- ❖ As we mentioned earlier, the last point of thermocouple material is known as the *cold junction*. The amount of output the t/c produces is determined by the difference between the hot junction and the cold junction temperatures. The cold junction temperature must be known to accurately determine the temperature.
- ❖ Lets look at the following examples;
 - If we had a thermocouple in a heat treat furnace and wanted to know what temperature it was in that furnace, we could attach a voltmeter to the cold junction and measure the voltage.
 - Let's say that the furnace is operating at 1000 deg. F. and it is 100 deg. F at the cool end of the T/C. Since we said that a T/C measures the difference between the hot and cold junctions, our formula would be:

$$1000 \text{ (hot junction)} - 100 \text{ (cold junction)} = 900 \text{ deg. F.}$$

- There seems to be a problem since we said that the furnace was at 1000 deg. F. This brings us to *COLD JUNCTION COMPENSATION*.
- ❖ *COLD JUNCTION COMPENSATION* is usually done automatically by the measuring instrument. The instrument measures the temperature at the cold junction and adds it back to the equation.

$$1000 \text{ (hot junction)} - 100 \text{ (cold junction)} = 900 \text{ deg. F} + 100 \text{ deg. F} \\ \text{(cold junction temp)} = 1000 \text{ deg F}$$

- This way the instrument indicates the actual temperature of the hot junction.
- ❖ This *COLD JUNCTION* compensator is usually located at the terminals on the back of the indicating instrument and you must maintain T/C material all the way to this point.
- ❖ For a thermocouple to function properly, there must be no other metals used between the hot junction and the cold junction. If wire is needed to connect the T/C to the indicating instrument, the leadwire must be made of the same material as the T/C.
 - It is acceptable to use terminal blocks and lugs made of plain copper in a thermocouple circuit as long as the positive and negative terminals are at the same temperature. (Example: terminal blocks in heads or spade lugs on wire)
- ❖ If you were to use plain copper wire instead of T/C extension wire to run to the instrument, your cold junction would be formed at the junction between the copper and the T/C wire. This junction would most likely not be at the same temperature as the back of the instrument where the compensator is located. This would then create an error in the indicated temperature.

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- ❖ If a customer were to use the wrong T/C extension wire, the same problem could appear. This is why we must use the correct T/C extension wire on our assemblies.
- ❖ It is also acceptable to have a third metal in the hot junction as long as that metal is at the same temperature as the thermocouple material.

REFERENCE TABLES

- ❖ There are printed tables that show the temperature vs. millivolt output figures. These reference tables are all based on the cold junction being at the freezing temperature of water (32 deg F or 0 deg C).
- ❖ We use these tables in our Certification Lab along with ice baths to make our cold junctions at 32 deg. F.
- ❖ Based on ASTM E-230

THERMOCOUPLE TYPES

- ❖ All thermocouples have a corresponding color code per ASTM E-230 (replaces ANSI MC96.1)
- ❖ Consult the Pyromation catalog page GEN-6 for a complete list of American color codes

BASE METAL THERMOCOUPLES

- ❖ Base metal thermocouples are known as Types E, J, K, T and N and comprise the most commonly used category of Thermocouple. The conductor materials in base metal thermocouples are made of common and inexpensive metals such as Nickel, Copper and Iron.
- ❖ **Type E:** The Type E thermocouple has a **Chromel (Nickel-10% Chromium)** positive leg and a **Constantan (Nickel- 45% Copper)** negative leg. Type E has a temperature range of -330 to 1600°F, has the highest EMF Vs temperature values of all the commonly used thermocouples, and can be used at sub-zero temperatures. Type E thermocouples can be used in oxidizing or inert atmospheres, and should not be used in sulfurous atmospheres, in a vacuum or in low oxygen environments where selective oxidation will occur. The color code for TYPE E wire is purple and red.
- ❖ **Type J:** The Type J thermocouple has an **Iron** positive leg and a **Constantan** negative leg. Type J thermocouples 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 using this thermocouple type in oxidizing environments above 1000°F. The temperature range for Type J is 32 to 1400°F and it has a wire color code of white and red.

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- ❖ **Type K:** The Type K thermocouple has a **Chromel** positive leg and an **Alumel (Nickel- 5% Aluminum and Silicon)** negative leg. Type K is recommended for use in oxidizing and completely inert environments. Because it's oxidation resistance is better than Types E, J, and T they find widest use at temperatures above 1000°F. Type K, like Type E should not be used in sulfurous atmospheres, in a vacuum or in low oxygen environments where selective oxidation will occur. The temperature range for Type K is -330 to 2300°F and it's wire color code is yellow and red.

- ❖ **Type N:** The Type N thermocouple has a **Nicrosil (Nickel-14% Chromium- 1.5% Silicon)** positive leg and a **Nisil (Nickel- 4.5% Silicon- .1% Magnesium)** negative leg. Type N is very similar to TYPE K but is less susceptible to selective oxidation effects. Type N should not be used in a vacuum or in reducing atmospheres in an unsheathed condition. The temperature range is 32-2300 deg F and its wire color code is orange and red.

- ❖ **Type T:** The Type T thermocouple has a **Copper** positive leg and a **Constantan** negative leg. Type T thermocouples can be used in oxidizing, reducing or inert atmospheres, except the copper leg restricts their use in air or oxidizing environments to 700°F or below. The temperature range for Type T is -330 to 700°F and it's wire color code is blue and red.

NOBLE METAL THERMOCOUPLE TYPES

- ❖ Noble Metal Thermocouples are another category of thermocouples and are made of the expensive precious metals Platinum and Rhodium. There are three types of noble metal thermocouples:
 - **Type B (Platinum/Platinum-30% Rhodium)**
 - **Type R (Platinum/Platinum-13% Rhodium)**
 - **Type S (Platinum/Platinum-10% Rhodium)**

- ❖ Types R and S have temperature ranges of 1000 to 2700°F and Type B thermocouples have a temperature range of 32 to 3100°F.

- ❖ As can be seen above, the difference between these three thermocouples is the amount of Rhodium contained in the negative leg. Types R and S can exhibit excessive grain growth in the platinum when exposed to the higher end of its temperature range. The increased amount of Rhodium in the Type B thermocouple helps to reduce the grain growth problem allowing for a slightly increased temperature range.

- ❖ Noble metal thermocouples are intended for use in oxidizing or inert atmospheres. They must not be used in reducing atmospheres or in applications containing metallic or nonmetallic vapors. Noble metal thermocouples are soft and prone to being damaged if mishandled. These thermocouple assemblies are usually assembled in ceramic insulators and supplied with ceramic protection tubes. Noble metals should never be supplied in metal protection tubes only. The color code for Types R and S is black and red, and the color code for Type B is gray and red.

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Refractory Metal Thermocouples

- ❖ Refractory Metal Thermocouples are the last category of thermocouple that Pyromation manufactures. These thermocouples are made of the exotic metals Tungsten and Rhenium, which are expensive, difficult to manufacture, brittle, and must be handled carefully. There are three types of refractory metal thermocouples:
 - **Type G (Tungsten/Tungsten 26% Rhenium)**
 - **Type D (Tungsten 3% Rhenium/Tungsten 26% Rhenium)**
 - **Type C (Tungsten 5% Rhenium/Tungsten 26% Rhenium)**
- ❖ (Note: The Type designations listed for the refractory thermocouples are industry standard designations, not standardized thermocouple types)
- ❖ All of these types have a temperature range of 32-4200 deg F. Refractory metal thermocouples are normally used in vacuum furnaces beyond the temperature capabilities of platinum. They are seldom used below approximately 2500°F since there are other thermocouple types more suited for the lower temperatures. Refractory metal thermocouples and their associated refractory metal protection tubes must not be used in the presence of oxygen at temperatures above 500°F.
- ❖ The color code for refractory thermocouples are:
 - Type G: White with blue tracer and red
 - Type D: White with yellow tracer and red
 - Type C: White with red tracer and red

LIMITS OF ERROR

- ❖ Tolerances now covered by ASTM E-230
- ❖ T/C wire is manufactured, then tested and sorted by accuracy.
- ❖ Refer to Pyromation catalog page GEN-5

THERMOCOUPLE RULES OF THE ROAD

- ❖ The most important rule to remember when manufacturing thermocouples is that ***red is always negative!*** (For domestic manufacturers)
- ❖ The second most important rule to remember is that ***red is always negative!*** Regardless of the T/C type, the red leg is the negative leg. This is different than your car battery or a DC circuit.
- ❖ Each thermocouple type has a different color code, which is shown on the handout. This will allow you to make sure that you are using the right calibration plug or jack with the right T/C.

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- ❖ *It is very important to memorize the color codes for types K, J, T, E, and N.*
- ❖ Thermocouple types J and K have one leg, which is magnetic. This is one of the easiest ways to determine polarity if there is no color-coding to help (as with MgO T/C's). If you were to refer to the THERMOCOUPLE TYPE COLOR CODE catalog handout, it has a column that indicates the magnetic leg.
- ❖ On the type J thermocouple, the *POSITIVE* leg is strongly magnetic. According to the handout, the white leg would be the magnetic leg.
- ❖ With the type K T/C, the *RED OR NEGATIVE* leg is the magnetic leg. It is not as strongly magnetic and can be hard to detect on smaller diameter wire.
- ❖ These are the only two types of thermocouples that have a magnetic leg so if a magnet sticks to one of the wires, you know it is type K or J.
- ❖ Color codes and magnetic legs are just tools to help assure that our connections are made properly.

THERMOCOUPLE MYTHS

- ❖ *There should never be a third metal in the hot junction*
To create a thermocouple junction, all that is needed is to electrically short the ends together. Butting the wire ends against a metal surface will create a junction. Remember, that the thermocouple signal is generated over the entire length of wire.
- ❖ *You must use special limits of error extension wire if your thermocouple is special limits*
This is not necessary *if* the extension wire is outside the temperature gradient area. Although the signal is generated over the entire length of wire, the important area is the gradient between the hot and ambient areas.
- ❖ *Non-thermocouple materials cannot be used in the thermocouple circuit.*
It is permissible to use non-thermocouple materials as terminal blocks or splices as long as there is no temperature gradient across these devices.
- ❖ *I can get an average temperature just by wiring my thermocouples in parallel.*
To get a true average, all thermocouples in a parallel circuit must be the same length or have the same resistance.
- ❖ *The largest possible extension wire should be used to connect a thermocouple.*
This phrase used to be true 30 years ago before there was solid-state electronics. The old instruments were Voltage based circuits and resistance was critical. The newer solid-state electronics are current based so extension wire resistance is not important.