



BLACK LAB SYSTEM
TECHNICAL NOTE #113

SUBJECT: Thermocouple Principals

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REV # 0

THERMOCOUPLE THEORY

A Thermocouple is commonly thought of as a pair of dissimilar wires connected at one end called the measuring junction. It was once thought that this thermocouple junction produced a voltage proportional to its temperature environment. While this is an easy concept to grasp and it provides a good correlation to what actually happens, it now appears to be mostly bunk. The actual thermoelectric effect is actually developed along the entire length of the wires, from the measuring junction to the reference junction, and is driven by the temperature gradients along the wires. This theory is called the “gradient” theory.

This theory is described in very good detail in a paper entitled [Thermocouple Fundamentals by Richard M. Park](#). Mr. Park made a career of studying thermocouples while at [Marlin Manufacturing](#) in Cleveland, Ohio. Besides the gradient theory, this paper also covers standard TC types, initial accuracy, selection factors, and decalibration and drift.

It should be noted that the stated accuracy for thermocouples applies only to new, unused, homogeneous material. Thermocouple performance depends on the metallurgical and chemical properties being uniform along the entire length of the thermocouple. In use, different parts of the thermocouple experience different operating conditions that causes those parts to become “different” and therefore, no longer homogeneous. Some factors that may cause a thermocouple to change are:

Bending – causes work hardening of the material, most often in the zone of highest temperature gradient.

Chemical attack – Different elements are subject to chemical attack which changes their uniformity. Things like oxygen, hydrogen, sulfur, etc., all combine with the thermoelectric material in varying degrees at different temperatures.

High temperature – Long exposures at elevated temperature causes some thermoelectric elements to change metallurgical properties. Material can either migrate to or from the thermocouple elements.

STANDARD THERMOCOUPLE TYPES AND COLORS

TYPE	Color Coding			Alloy Combination		Maximum Temp. Range
	+ Lead	- Lead	Sheath	+ Lead	- Lead	
J	White	Red	Black	Iron (magnetic)	Constantan	-210 to 1200°C -346 to 2193°F
K	Yellow	Red	Yellow	Chromel	Alumel (magnetic)	-270 to 1372°C -454 to 2501°F
T	Blue	Red	Blue	Copper	Constantan	-270 to 400°C -454 to 752°F
E	Purple	Red	Purple	Chromel	Constantan	-270 to 1000°C -454 to 1832°F
N	Orange	Red	Orange	Nicrosil	Nisil	-270 to 1300°C -454 to 2372°F
R	Black	Red	Green	Platinum – 13% Rhodium	Platinum (soft)	-50 to 1768°C -58 to 3214°F
S	Black	Red	Green	Platinum – 10% Rhodium	Platinum (soft)	-50 to 1768°C -58 to 3214°F
B	Gray	Red	Gray	Platinum – 30% Rhodium	Platinum – 6% Rhodium	0 to 1820°C 32 to 3308°F

The following tolerance table is extracted from ASTM E230. It applies only to new, unused thermocouples. Tolerances are listed as degrees or percent. Use whichever is greater.

TYPE	Temperature Range	Standard Limits of Error	Special Limits of Error	Temperature Range	Standard Limits of Error	Special Limits of Error
J	0 to 750°C	2.2°C or 0.75%	1.1°C or 0.4%	32 to 1382°F	4.0°F or 0.75%	2.0°F or 0.4%
K	0 to 1250°C	2.2°C or 0.75%	1.1°C or 0.4%	32 to 2282°F	4.0°F or 0.75%	2.0°F or 0.4%
	-200 to 0°C	2.2°C or 2.0%	---	-328 to 32°F	4.0°F or 2.0%	---
T	0 to 350°C	1.0°C or 0.75%	0.5°C or 0.4%	32 to 662°F	1.8°F or 0.75%	1.0°F or 0.4%
	-200 to 0°C	1.0°C or 1.5%	---	-328 to 32°F	1.8°F or 1.5%	---
E	0 to 900°C	1.7°C or 0.5%	1.0°C or 0.4%	32 to 1652°F	3.0°F or 0.5%	1.8°F or 0.4%
	-200 to 0°C	1.7°C or 1.0%	---	-328 to 32°F	3.0°F or 1.0%	---
N	0 to 1300°C	2.2°C or 0.75%	1.1°C or 0.4%	32 to 2372°F	4.0°F or 0.75%	2.0°F or 0.4%
	-270 to 0°C	2.2°C or 2.0%	---	-454 to 32°F	4.0°F or 2.0%	---
R	0 to 1450°C	1.5°C or 0.25%	0.6°C or 0.1%	32 to 2642°F	2.7°F or 0.25%	1.0°F or 0.1%
S	0 to 1450°C	1.5°C or 0.25%	0.6°C or 0.1%	32 to 2642°F	2.7°F or 0.25%	1.0°F or 0.1%
B	800 to 2320°C	0.5%	---	1472 to 3092°F	0.9%	---

The root of all temperature measurement is the International Temperature Scale as revised in 1990 (ITS-90). This document defines many fixed point temperature (boiling points and freezing points) and the relationship of thermocouples to this scale. This is readily defined by [NIST](#) in their Monograph 175. This information can also be obtained online by going to the [NIST ITS-90 Thermocouple Database](#). There you can view or download [thermocouple tables and coefficients](#).

Additional information is provided by the American Society for Testing and Materials ([ASTM](#)), Some of the ASTM documents pertinent to temperature and thermocouples are listed below.

[MNL12 Manual on the Use of Thermocouples in Temperature Measurement: Fourth Edition](#) (Formerly STP 470B) Includes principles, circuits, standard electromotive force (emf) tables, stability and compatibility data, installation techniques, and other information that will aid both the beginner and the experienced user of thermocouples. Completely revised in accordance with the International Temperature Scale of 1990 (ITS-90). This is a highly definitive reference for the practical thermocouple user.

[E230-03 Standard Specification and Temperature-Electromotive Force \(EMF\) Tables for Standardized Thermocouples...](#)

[E988-96\(2002\) Standard Temperature-Electromotive Force \(EMF\) Tables for Tungsten Rhenium Thermocouples](#)

[E1751-00 Standard Guide for Temperature Electromotive Force \(emf\) Tables for Non-Letter Designated Thermocouple Combinations](#)

[E1129/E1129M-98\(2002\) Standard Specification for Thermocouple Connectors](#)

[E1684-00 Standard Specification for Miniature Thermocouple Connectors](#)

[E1350-97 Standard Test Methods for Testing Sheathed Thermocouples Prior to, During, and After Installation](#)

[E220-02 Standard Test Method for Calibration of Thermocouples By Comparison Techniques...](#)

[E452-02 Standard Test Method for Calibration of Refractory Metal Thermocouples Using a Radiation Thermometer](#)

Another organization that has reference documents pertinent to thermocouples is the American National Standards Institute ([ANSI](#)). They publish standard MC 96.1.

And then Omega Engineering has an excellent [technical reference section](#) with the following topics.

- [Thermocouple Selection Guide](#)
- [Thermocouple - A Reference Guide](#)
- [Using Thermocouples](#)
- [Infrared Selection Guide](#)
- [Introduction to Thermocouples](#)
- [Introduction to Practical Temperature Measurements](#)
- [Properties of Thermocouple and Extension Grade Wire](#)
- [Sheath Selection Guide](#)
- [Physical Properties of Thermoelement Materials](#)
- [Reference Guide - Temperature Limit Vs. Sheath Size](#)
- [Nicrosil/Nisil Type N Thermocouple](#)
- [Choice of Sheathing for Mineral Insulated Thermocouples](#)
- [Temperature Properties of Some Metals, Elements and Compour](#)
- [Reference Junction Principles](#)
- [Properties of Teflon® Insulation](#)
- [Wire Insulation Identification & Application Guide](#)
- [Temperature Measurement Guide](#)
- [Wire Color Codes and Limits of Error](#)