Temperature Measurement

Gabriel Daniel Fahrenheit developed the mercury thermometer in 1714. Mercury has the desirable property of a low freezing point (-38.7 C), a high boiling point (357 C) and a relatively constant coefficient of thermal expansion. Being highly toxic, expensive, slow to respond and impractical to interface with a computer are significant issues preventing its wide spread use.

Fahrenheit used a mixture of ice, salt and water as the zero degree reference point and the temperature of the human body as a 96 degree reference point.

Anders Celsius created his temperature scale in 1742. Originally zero degrees was the boiling point of water and 100 degrees was the freezing point. These points were later reversed.

Temperature Scales

As described above original temperature scales were based on certain fixed points. A more rational definition is one based on the Second Law of Thermodynamics. The efficiency of a Carnot engine, η, provides a definition of the zero point and a conceptual way of defining intermediate temperatures.

$$\eta = \frac{W}{Q_H} = 1 - \frac{T_C}{T_H} = 1 - \frac{Q_C}{Q_H}$$

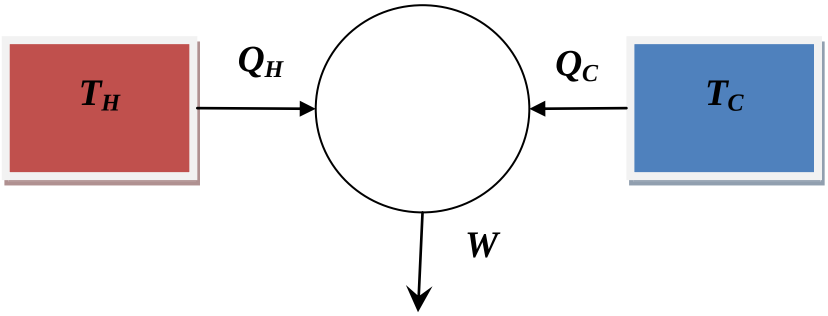


Figure 1. Carnot engine diagram - where heat flows from a high temperture T_H furnace through the fluid of the "working body" (working substance) and into the cold sink T_C, thus forcing the working substance to do mechanical work W on the surroundings, via cycles of contractions and expansions.

The size of a degree based on the two common scales, Rankine (Fahrenheit) and Kelvin (Celsius), is described above. The Rankine and Kelvin scale are thermodynamic scales and can therefore be used in equations such as the ideal gas equation of state. The ideal gas equation, $T = {}^{PV}\!/_{nR}$, provides a practical alternative to the theoretical Carnot engine. Here P is the absolute pressure of the gas; V is the volume of the gas; n is the amount of substance of the gas, usually measured in moles; R is the gas constant (which is 8.314472 $\mathrm{JK^{-1}mol^{-1}}$ in SI units); and T is the absolute temperature.

Table 1. The common temperature scales and fixed temperature points.

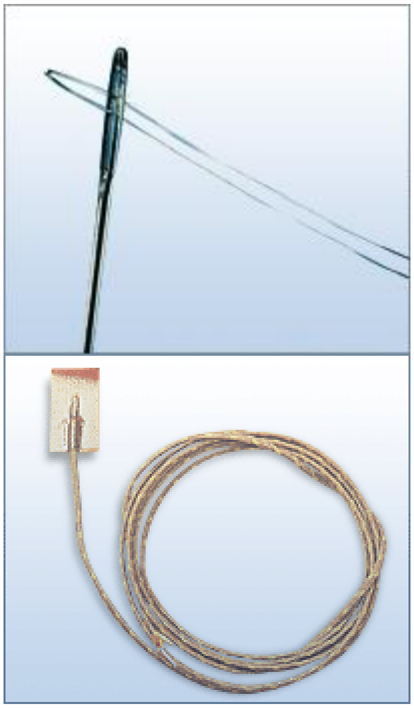
	Kelvin	Rankine	Celsius	Fahrenheit
Absolute Zero	0	0	-273	-492
Melting Ice	273	460	0	32
Boiling Water	373	572	100	212

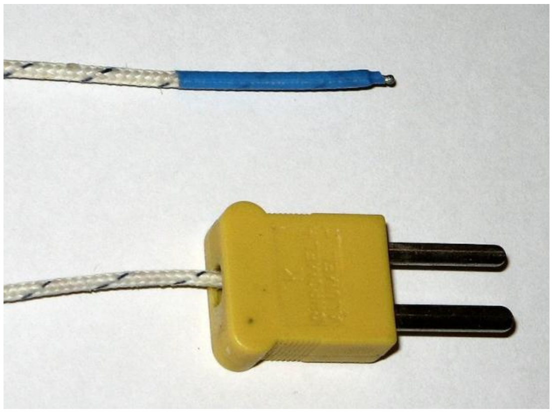
Five main temperature sensors

These include thermocouples, resistance temperature detectors (RTDs), thermistors, infrared thermometers, and fiber-optic temperature sensors. The glass thermometer is not well suited for most industrial environments (fragile, limited temperature range and require a manual reading).

Thermocouples

Thermocouples are still the most widely used temperature sensor in industrial manufacturing environments. Thermocouples are simply two wires made of different metals that are joined at the end. The joined end is called the measurement junction. The other end is called the reference junction. If the measurement and reference junctions are at different temperatures an Electromotive Force, EMF, or voltage potential is created. The resulting voltage is a function of the temperature difference and the types of metals used.





In 1821, the German–Estonian physicist Thomas Johann Seebeck discovered that when any conductor is subjected to a thermal gradient, it will generate a voltage. This is now known as the thermoelectric effect or Seebeck effect. Our understanding of the physics underlying his observations has evolved considerably in the intervening centuries and is beyond the scope of this course.

Because thermocouples are still the most widely used temperature sensor they remain the workhorse of the temperature sensor world. They come in a multitude of sizes, shapes, mixtures of metals and are designed for a wide range of temperatures and conditions.

Table 2. properties of several different thermocouple types.

ANSI Type	Temperature range °C	Sensitivity	IEC Color code
K	0 to +1100	41 µV/°C	(chromel–alumel) is the most common general purpose thermocouple
J	0 to +700	55 µV/°C	(iron–constantan) is less popular than type K but slightly more sensitive. Nonoxidizing environments
R	0 to +1600	10 µV/°C	(13% rhodium/platinum-pure platinum) Highly stable, high temperature
S	0 to 1600	10 µV/°C	(10% Rhodium/platinum-pure platinum) Used as the standard of calibration for the melting point of gold (1064.43 °C).
B	+200 to +1700	10 µV/°C	(30% rhodium/platinum- 6% rhodium/platinum) Highly stable, high temperature
T	−185 to +300	43 µV/°C	(Copper-Constantan) reducing environments low temperature TC used in our lab
E	0 to +800	68 µV/°C	(chromel–constantan) well suited to cryogenic use. Additionally, it is non-magnetic. highest emf output of any standard metallic thermocouple.

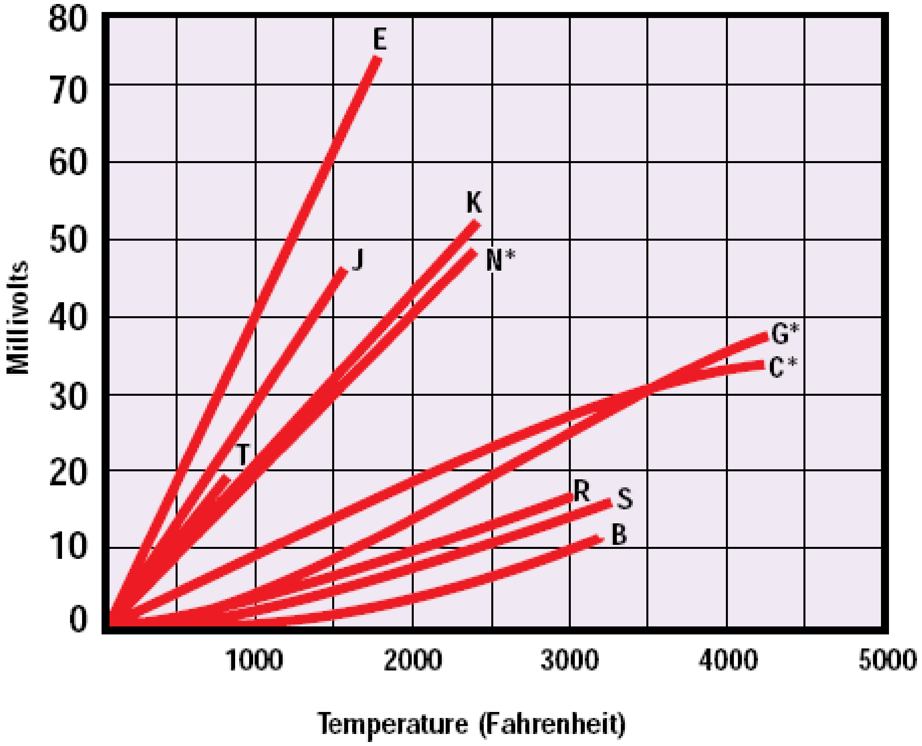


Figure 2. Static calibration curves of common thermocouples.

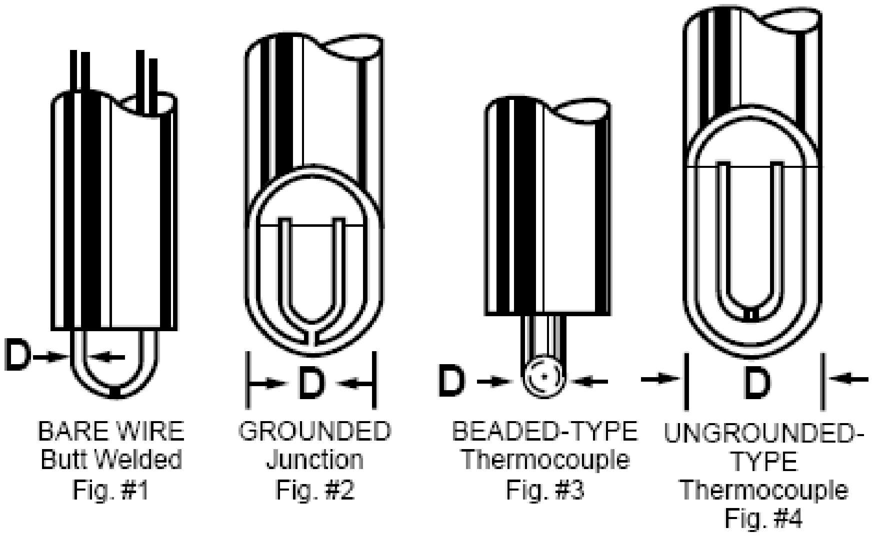


Figure 3. Standard thermocouple probe configurations.

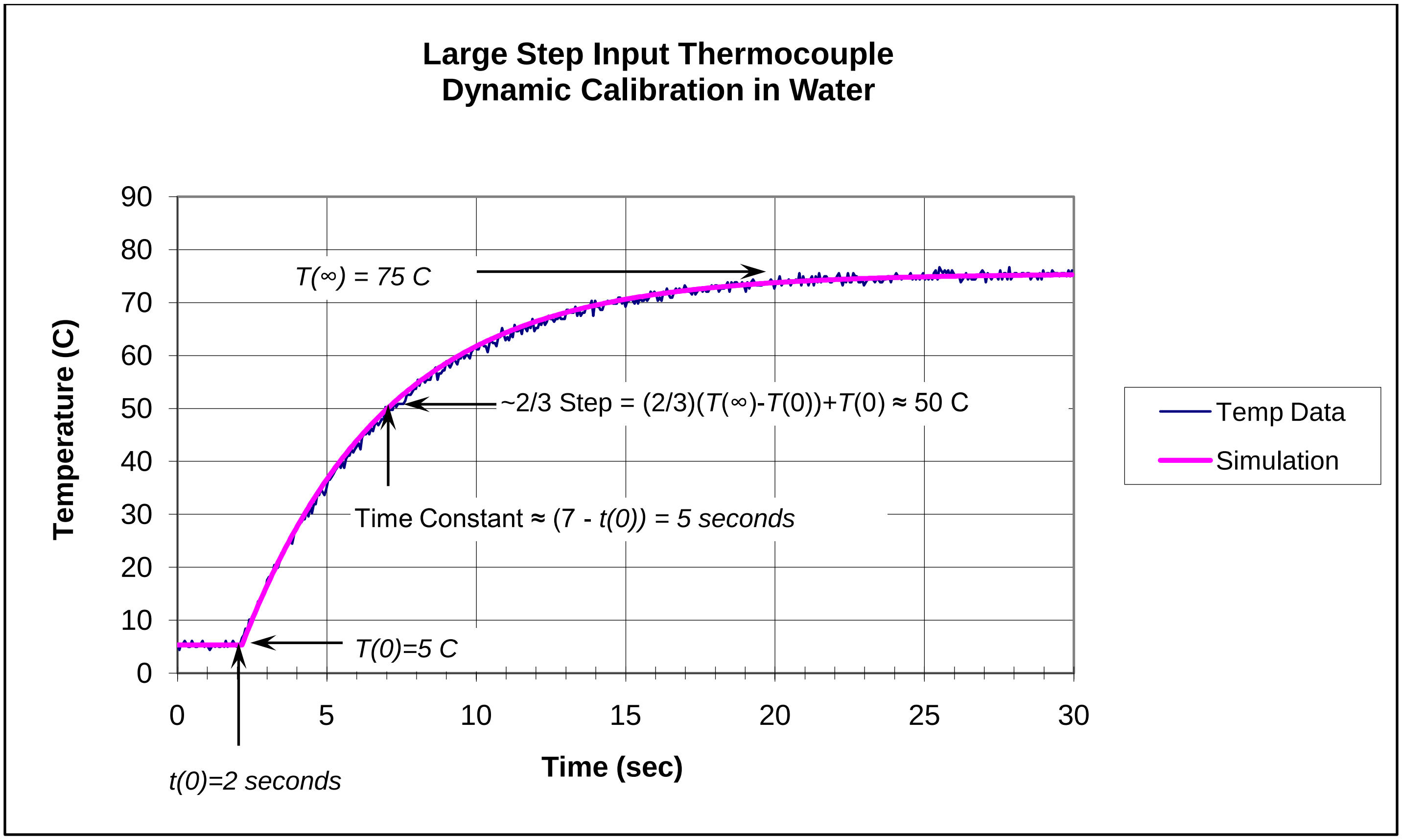


Figure 4. A typical dynamic response of a thermocouple subjected to a step input temperature change. In this graph, the initial temperature, T_0, is approximately 5 C and the final temperature, T_∞, is approximately 75 C. The simulation was calculated using these parameters and Equation (1). Time, t, in Equation (1) was offset to start the transient at 2 seconds (where the temperature change began).