SEEBECK EFFECT & THERMOCOUPLES

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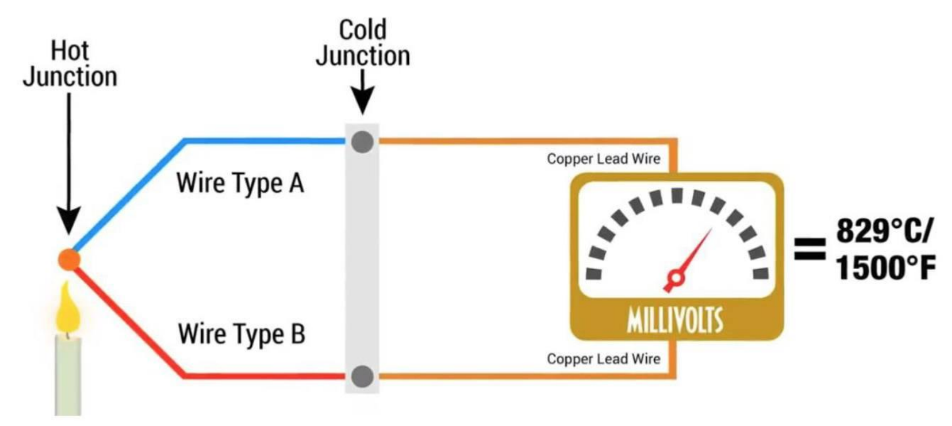
INTRODUCTION

The Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances. When heat is applied to one of the two conductors or semiconductors, heated electrons flow toward the cooler conductor or semiconductor. If the pair is connected through an electrical circuit, direct current (DC) flows through that circuit.



SEEBECK EFFECT

In 1821, German physicist Thomas Seebeck discovered that when two wires made from dissimilar metals are joined at two ends to form a loop, and if the two junctions are maintained at different temperatures, a voltage develops in the circuit. This phenomenon is therefore named after him.

When heat is applied to one of the two conductors or semiconductors, that metal heats up. Consequently, the valence electrons present in this metal flow toward the cooler metal. This happens because electrons move to where energy (in this case, heat) is lower. If the metals are connected through an electrical circuit, direct current flows through the circuit.

However, this voltage is just a few microvolts per kelvin temperature difference. Thermal energy is continuously transferred from the warmer metal to the cooler metal until eventually, temperature equilibrium is obtained.

The Seebeck effect and its resultant thermoelectric effect is a reversible process. If the hot and cold junctions are interchanged, valence electrons will flow in the other direction, and also change the direction of the DC current.

VIDEO TIME!

WHY'S IT RELATED TO THERMOCOUPLES?

The Seebeck effect is a classic example of an electromotive force (EMF) and leads to measurable currents or voltages in the same way as any other EMF. The local current density is given by below:

$$\mathbf{J} = \sigma(-\nabla V + \mathbf{E}_{\text{emf}}),$$

In general, the Seebeck effect is described locally by the creation of an electromotive field:

$$\mathbf{E}_{\text{emf}} = -S\nabla T,$$

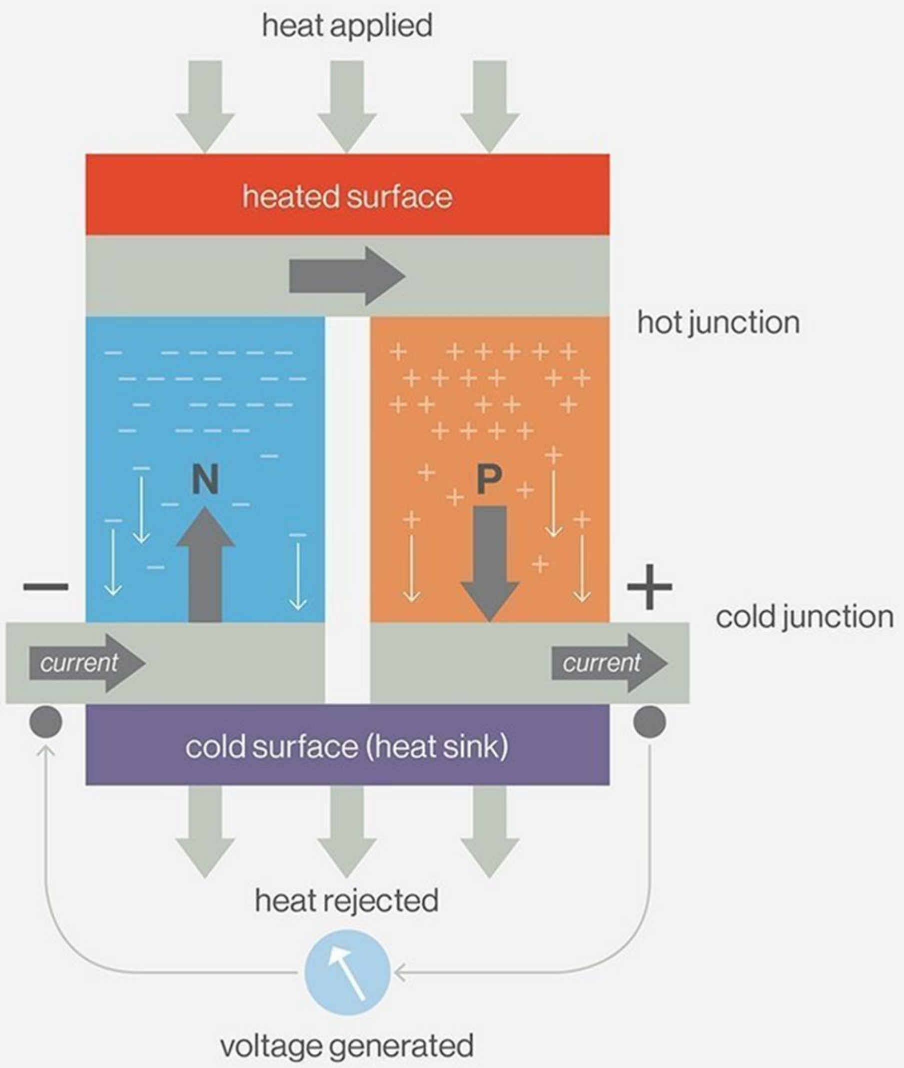
WHY'S IT RELATED TO THERMOCOUPLES?

if the system reaches a steady state, where J = 0, then the voltage gradient is given simply by the emf:

$$\nabla V = -S \nabla T$$

This simple relationship, which does not depend on conductivity, is used in the thermocouple to measure a temperature difference; an absolute temperature may be found by performing the voltage measurement at a known reference temperature.

Semiconductor Thermocouple Seebeck Effect



Source: mpoweruk

SEEBECK COEFFICIENT

The use of materials with a high Seebeck coefficient is one of many important factors for the efficient behaviour of thermoelectric generators and thermoelectric coolers. It may be positive or negative. In conductors that can be understood in terms of independently moving, nearly-free charge carriers, the Seebeck coefficient is negative for negatively charged carriers (such as electrons), and positive for positively charged carriers (such as electron holes).

SEEBECK COEFFICIENT

In practice the absolute Seebeck coefficient is difficult to measure directly, since the voltage output of a thermoelectric circuit, as measured by a voltmeter, only depends on differences of Seebeck coefficients. This is because electrodes attached to a voltmeter must be placed onto the material in order to measure the thermoelectric voltage. The temperature gradient then also typically induces a thermoelectric voltage across one leg of the measurement electrodes. Therefore, the measured Seebeck coefficient is a contribution from the Seebeck coefficient of the material of interest and the material of the measurement electrodes. This arrangement of two materials is usually called a thermocouple. The measured Seebeck coefficient is then a contribution from both and can be written as:

$$S_{AB} = S_B - S_A = \frac{\Delta V_B}{\Delta T} - \frac{\Delta V_A}{\Delta T}$$

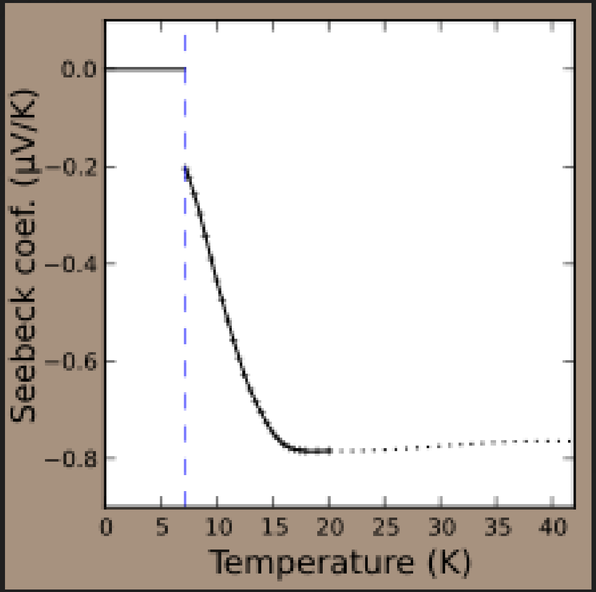
SEEBECK COEFFICIENT

Although only relative Seebeck coefficients are important for externally measured voltages, the absolute Seebeck coefficient can be important for other effects where voltage is measured indirectly. Determination of the absolute Seebeck coefficient therefore requires more complicated techniques and is more difficult, but such measurements have been performed on standard materials. These measurements only had to be performed once for all time, and for all materials; for any other material, the absolute Seebeck coefficient can be obtained by performing a relative Seebeck coefficient measurement against a standard material.

$$S(T) = \int_0^T \frac{\mu(T')}{T'} dT'$$

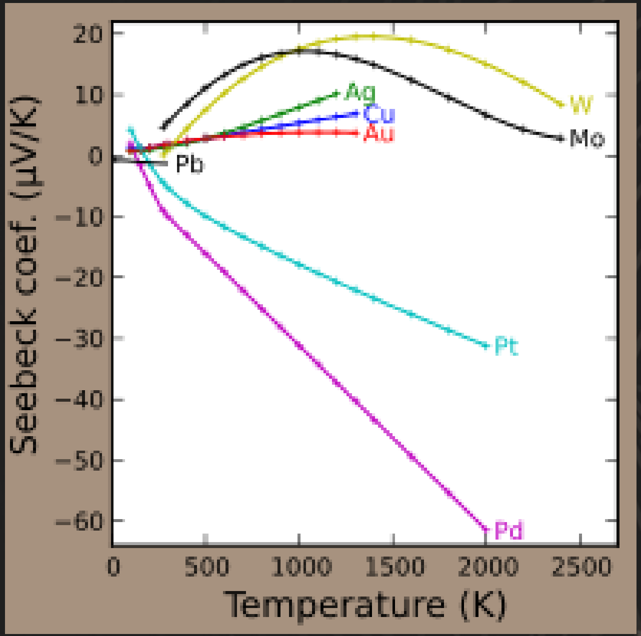
SEEBECK COEFFICIENT

Superconductors have zero Seebeck coefficient. By making one of the wires in a thermocouple superconducting, it is possible to get a direct measurement of the absolute Seebeck coefficient of the other wire, since it alone determines the measured voltage from the entire thermocouple. A publication in 1958 used this technique to measure the absolute Seebeck coefficient of lead between 7.2 K and 18 K.



SEEBECK COEFFICIENT

The combination of the superconductor-thermocouple technique up to 18 K, with the Thomson-coefficient-integration technique above 18 K, allowed determination of the absolute Seebeck coefficient of lead up to room temperature. By proxy, these measurements led to the determination of absolute Seebeck coefficients for *all materials*, even up to higher temperatures, by a combination of Thomson coefficient integrations and thermocouple circuits.



SEEBECK COEFFICIENT

Material	Seebeck coefficient *relative to platinum* (μV/K)
Selenium	900
Tellurium	500
Silicon	440
Germanium	330
Antimony	47
Nichrome	25
Molybdenum	10
Cadmium, tungsten	7.5
Gold, silver, copper	6.5
Rhodium	6.0
Tantalum	4.5
Lead	4.0
Aluminium	3.5
Carbon	3.0
Mercury	0.6
Platinum	0 (definition)
Sodium	-2.0
Potassium	-9.0
Nickel	-15
Constantan	-35
Bismuth	-72

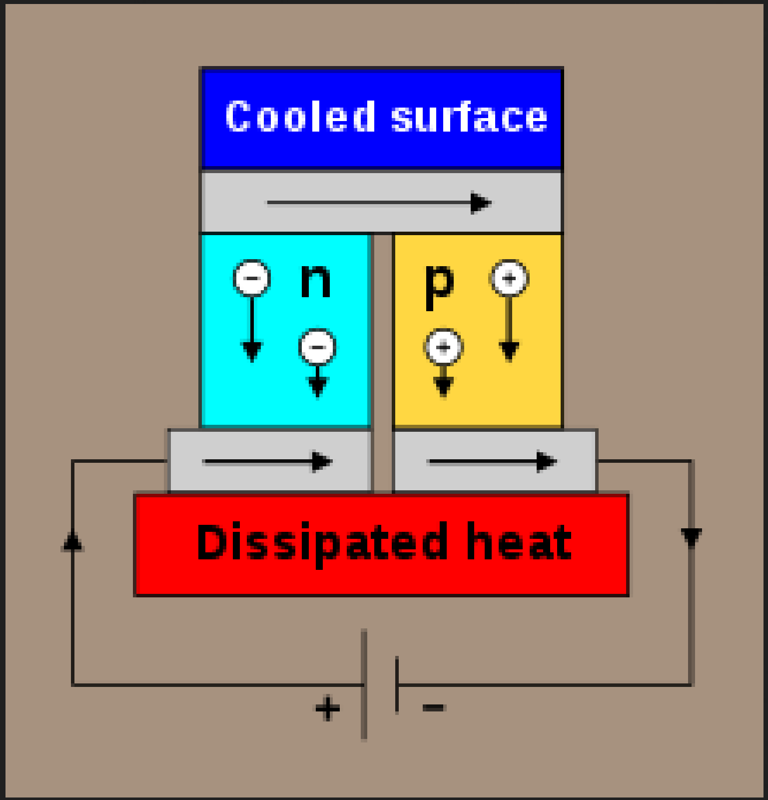
PELTIER EFFECT

In 1834, Jean Peltier, a French watchmaker, discovered another second thermoelectric effect that was later named the Peltier effect. Peltier observed that when a current flows through a circuit containing a junction of two dissimilar metals -- similar to the setup in the Seebeck effect -- heat is either absorbed or liberated at the junction. This absorption or liberation depends on the pair of metals used and the direction of the current.

$$\dot{Q} = (\Pi_\mathrm{A} - \Pi_\mathrm{B}) I,$$

$$S = \frac{\Pi}{T},$$

PELTIER EFFECT



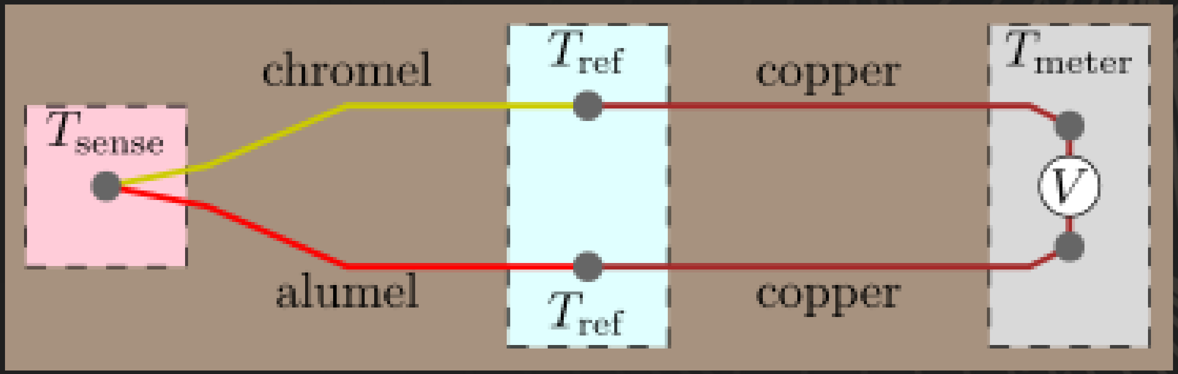
THOMSON EFFECT

In different materials, the Seebeck coefficient is not constant in temperature, and so a spatial gradient in temperature can result in a gradient in the Seebeck coefficient. If a current is driven through this gradient, then a continuous version of the Peltier effect will occur. This effect was predicted and later observed in 1851 by Lord Kelvin (William Thomson). It describes the heating or cooling of a current-carrying conductor with a temperature gradient.

$$\mathcal{K} = T\frac{dS}{dT}$$

THERMOCOUPLES

The standard configuration for thermocouple usage is shown in the figure. Briefly, the desired temperature T_{sense} is obtained using three inputs—the characteristic function $E(T)$ of the thermocouple, the measured voltage V, and the reference junctions' temperature T_{ref}. The solution to the equation: $E(T_{sense}) = V + E(T_{ref})$ yields T_{sense}. These details are often hidden from the user since the reference junction block (with T_{ref} thermometer), voltmeter, and equation solver are combined into a single product.



THERMOCOUPLES

The thermocouple's behaviour is captured by a characteristic function:

$$V = E(T_{\text{sense}}) - E(T_{\text{ref}}).$$

$$E(T) = \int^{T} S_{+}(T') - S_{-}(T') dT' + \text{const}$$

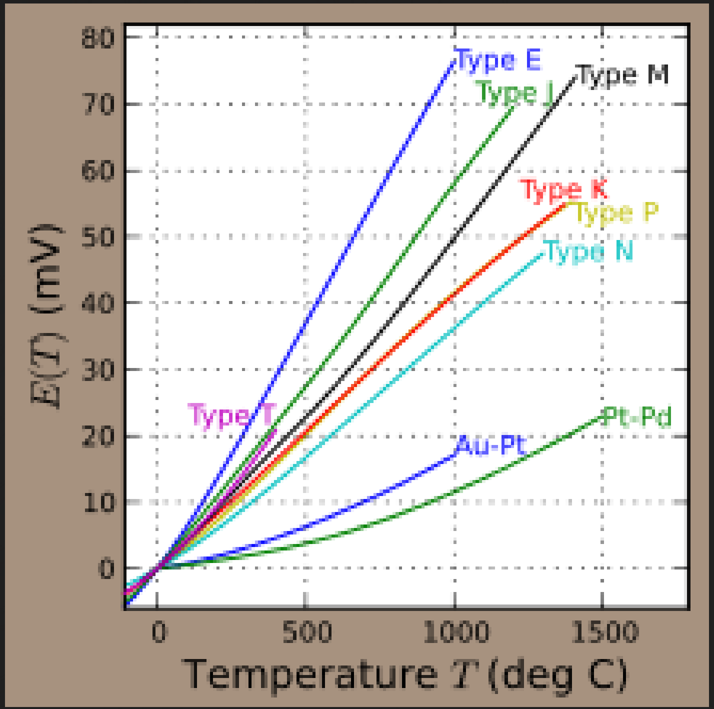
THERMOCOUPLES - REFERENCE JUNCTION

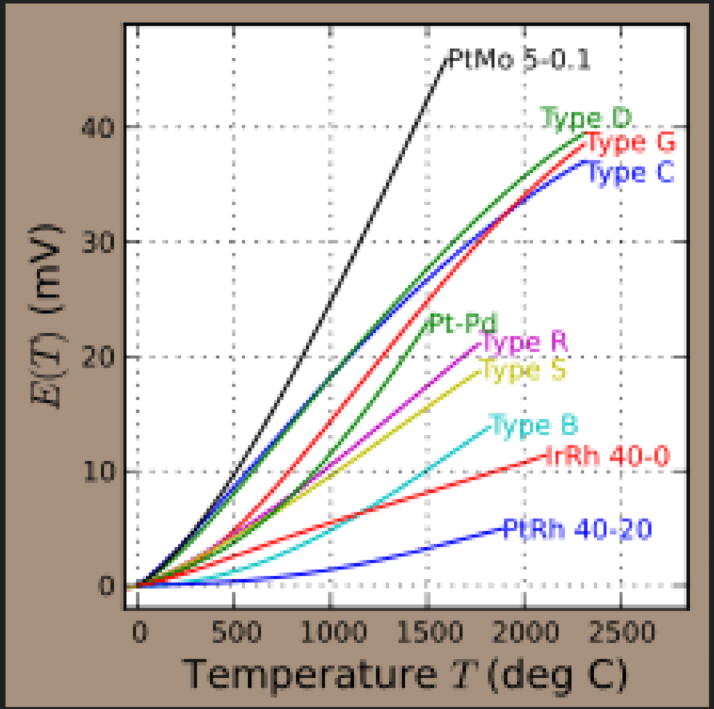
The temperature at the reference junctions must be already known. Two strategies are often used here:

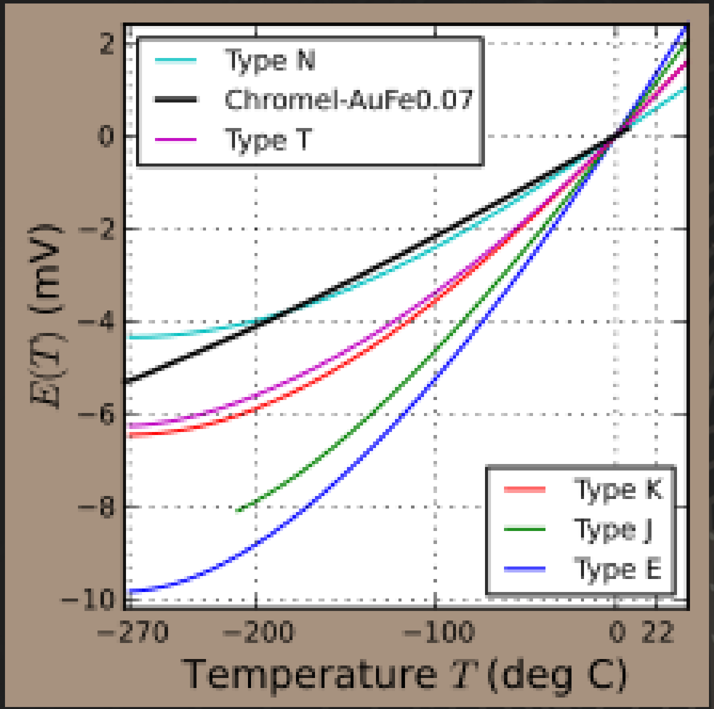
"Ice bath" method: The reference junction block is immersed in a semi-frozen bath of distilled water at atmospheric pressure. The precise temperature of the melting point phase transition acts as a natural thermostat.

Reference junction sensor (known as "cold junction compensation"): The reference junction block is allowed to vary in temperature, but the temperature is measured at this block using a separate temperature sensor. This secondary measurement is used to compensate for temperature variation at the junction block. The thermocouple junction is often exposed to extreme environments, while the reference junction is often mounted near the instrument's location. Semiconductor thermometer devices are often used in modern thermocouple instruments

THERMOCOUPLES – TYPES





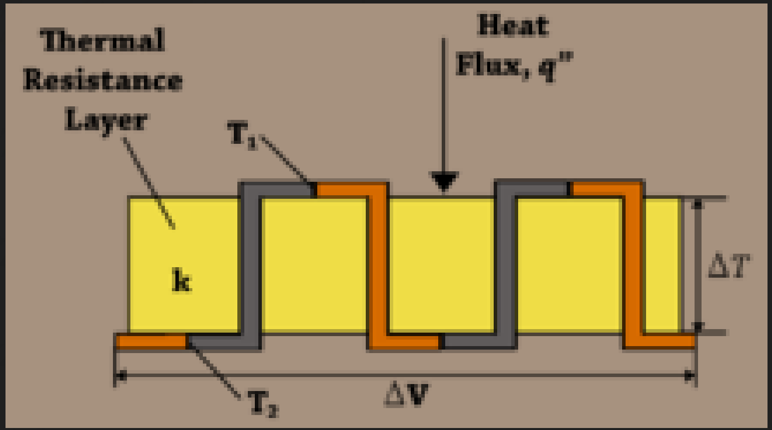


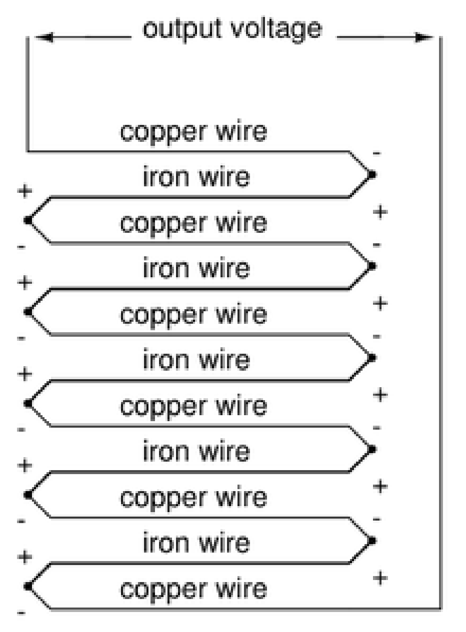
THERMOCOUPLES - TYPES

Type	Temperature range (°C)				Tolerance class (°C)		Color code		
	Continuous		Short-term		One	Two	IEC[30]	BS	ANSI
	Low	High	Low	High					
K	0	+1100	−180	+1370	−40 – 375: ±1.5 375 – 1000: ±0.004×T	−40 – 333: ±2.5 333 – 1200: ±0.0075×T			
J	0	+750	−180	+800	−40 – 375: ±1.5 375 – 750: ±0.004×T	−40 – 333: ±2.5 333 – 750: ±0.0075×T			
N	0	+1100	−270	+1300	−40 – 375: ±1.5 375 – 1000: ±0.004×T	−40 – 333: ±2.5 333 – 1200: ±0.0075×T			
R	0	+1600	−50	+1700	0 – 1100: ±1.0 1100 – 1600: ±0.003×(T−767)	0 – 600: ±1.5 600 – 1600: ±0.0025×T			Not defined
S	0	+1600	−50	+1750	0 – 1100: ±1.0 1100 – 1600: ±0.003×(T−767)	0 – 600: ±1.5 600 – 1600: ±0.0025×T			Not defined
B	+200	+1700	0	+1820	Not available	600 – 1700: ±0.0025×T	No standard	No standard	Not defined
T	−185	+300	−250	+400	−40 – 125: ±0.5 125 – 350: ±0.004×T	−40 – 133: ±1.0 133 – 350: ±0.0075×T			
E	0	+800	−40	+900	−40 – 375: ±1.5 375 – 800: ±0.004×T	−40 – 333: ±2.5 333 – 900: ±0.0075×T			
Chromel/AuFe	−272	+300	N/A	N/A	Reproducibility 0.2% of the voltage. Each sensor needs individual calibration.				

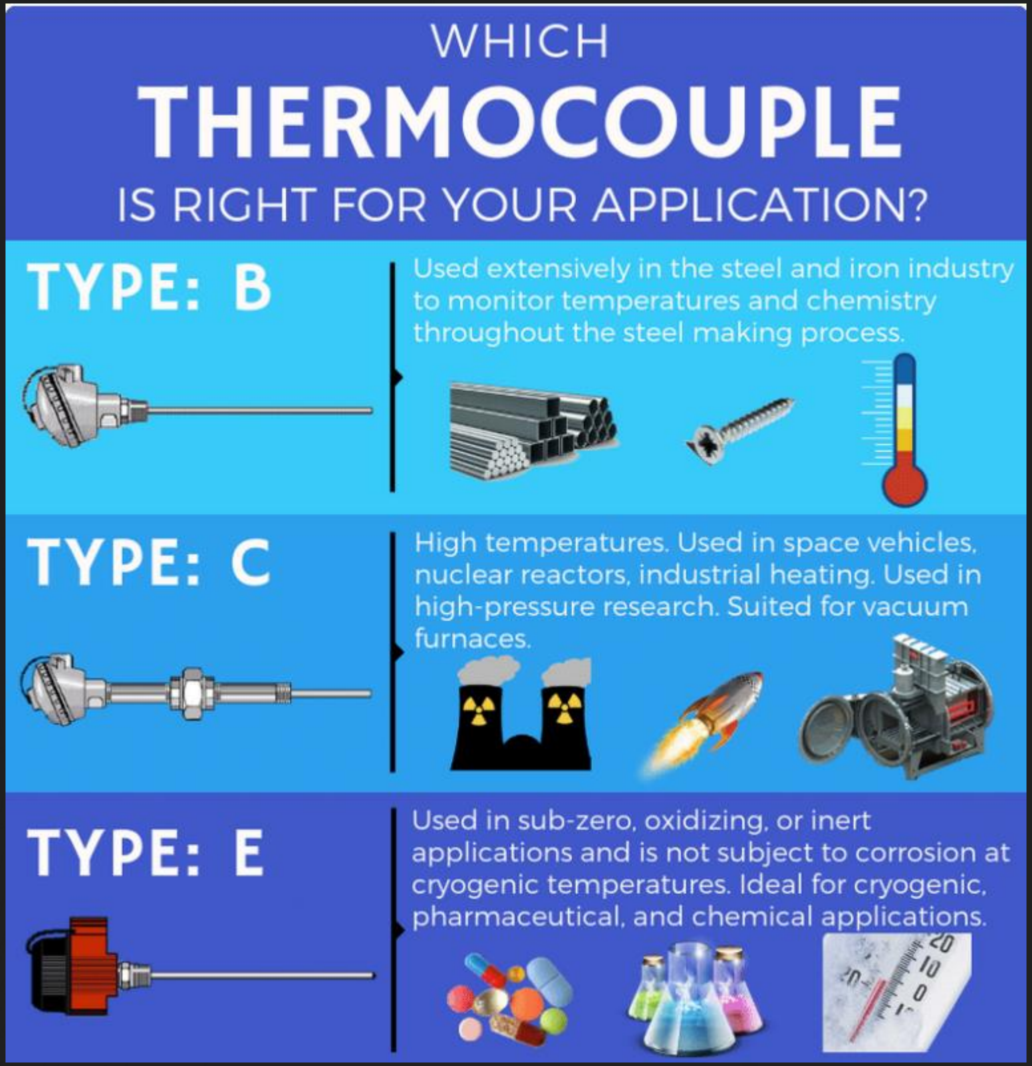
THERMOPILES

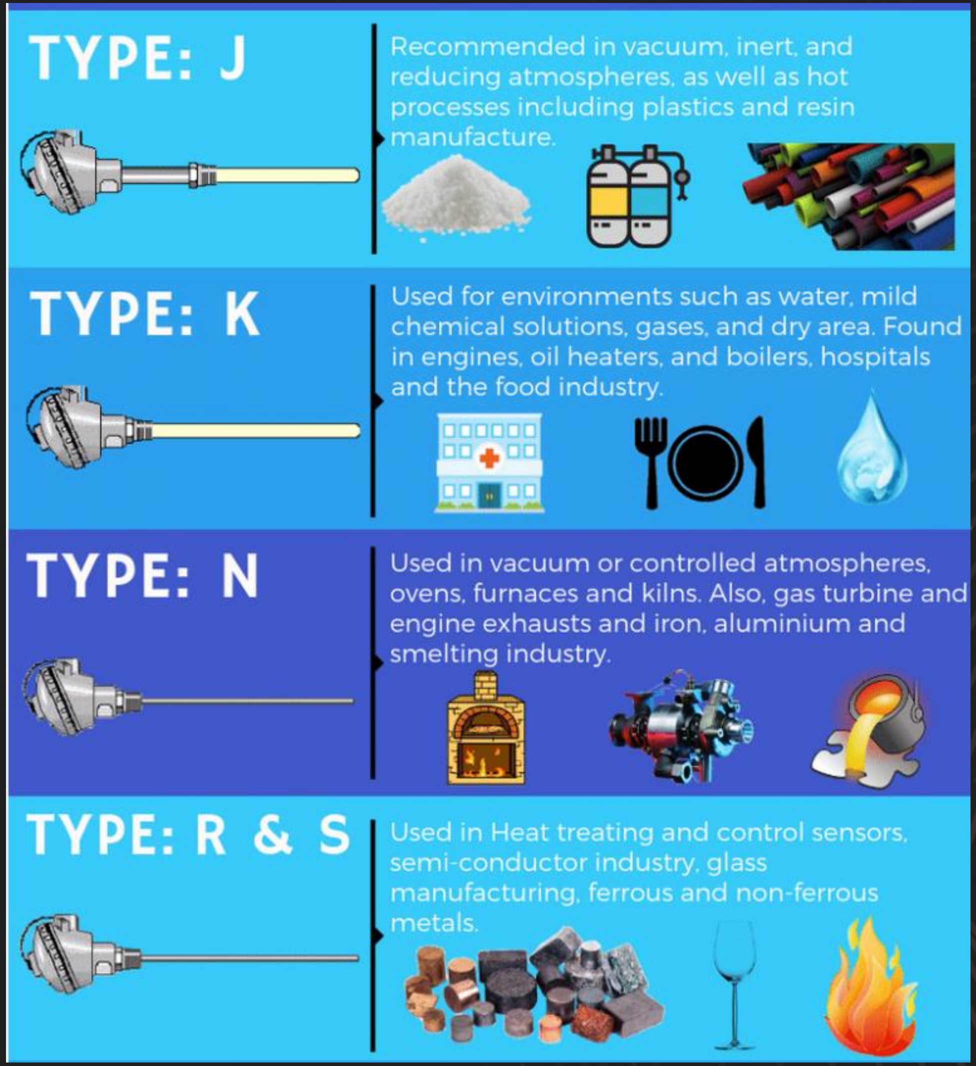
A thermopile is composed of several thermocouples connected usually in series or, less commonly, in parallel. Thermopiles are also used to generate electrical energy from, for instance, heat from electrical components, solar wind, radioactive materials, laser radiation, or combustion. The process is also an example of the Peltier effect (electric current transferring heat energy) as the process transfers heat from the hot to the cold junctions.





THERMOCOUPLES - APPLICATIONS





THERMOCOUPLES - CHALLENGES

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LA FINE

GRAZIE PER L’ATTENZIONE :)