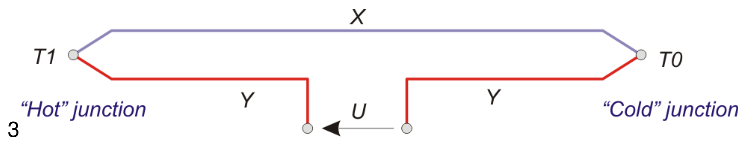
Thermocouple is one of the most popular type of temperature sensors used in industry. Thermocouple uses thermoelectric effect (Seebeck's effect).

Thermoelectric effect

Consider an open electrical circuit, consisting of two conductors X and Y (metals or alloys) as in the drawing below:



Thermoelectric effect

If both junctions of metals (alloys) are placed in two different temperatures (T1 and T0) then at the ends of the circuit a potential difference is created (U). This phenomena is called, from the name of the discoverer, the Seebeck's effect. The potential difference is depended on the type of metals (alloys) used. The greater the difference of temperatures T0 and T1 is, the stronger the Seebeck's effect is.
It is possible to calculate the T1 temperature of hot junction if the temperature of cold junction T0 and the potential difference U are know. This is the way the thermocouples are used for determining e.g. gas temperatures in stacks.

The table below presents the thermoelectric characteristics of different metals and alloys. Seebeck's coefficient α for metal X is referred to Platinum = α coefficient is characteristic for a particular metal when this is paired with platinum (Pt). For this reason α coefficient for platinum equals 0.

Material	Seebeck's coefficient [uV/K] @ 273K
Bismuth (Bi)	-72
Constantan (55% Cu + 44% Ni + 1% Mn)	-35
Nickel (Ni)	-15
Platinum (Pt)	0
Carbon (C)	3,0
Aluminium (Al)	3,5
Rod (Rh)	6,0
Copper (Cu)	6,5
Gold (Au)	6,5
Silver (Ag)	6,5
Iron (Fe)	19
Nichrome (80% Ni + 20% Cr) – nickel 80-20, chromium A	25
Chromel® (90% Ni + 10% Cr)	21,7
Alumel® (95% Ni + 2% Mn + 2% Al + 1% Si)	-17,3
Platinum-Rhodium Alloy (90% Pt + 10% Rh)	1,4
Nicrosil (14.2% Cr + 1.4%Si + Ni)	29,3
Nisil (4.4% Si + 0.1%Mg + Ni)	-11

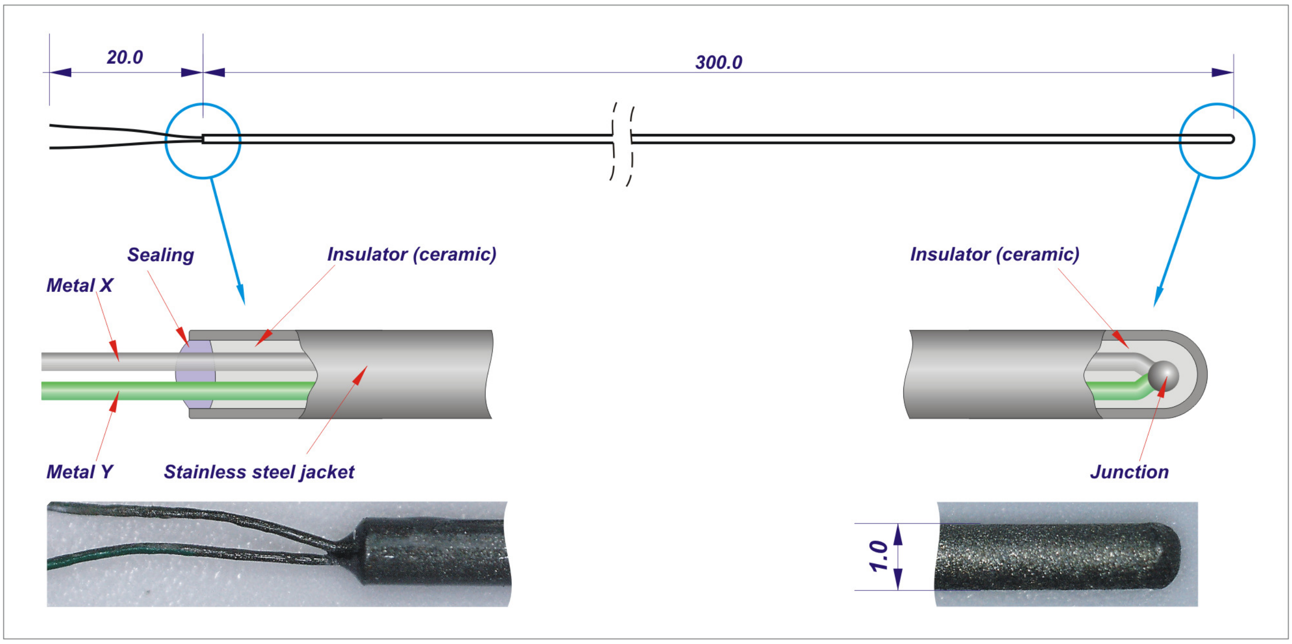
Seebeck's coefficient for a selected metals (referred to Platinum)

α coefficient is depended on the temperature (the table presents coefficient's value in 0℃). Thermocouple's response signal is non-linear.
With the help of the table, it is possible to estimate a constant for thermocouple made of materials X and Y, by deducting α coefficients of thermocouple materials.
For example, a NiCr-Ni thermocouple is made of Nichrome (X) and Nickel (Y), and has the coefficient:

$$\alpha_X - \alpha_Y = 25\mu V/K - (-15\mu V/K) \approx 40\mu V/K$$

The construction of thermocouple sensors

Thermocouple is produced as two wires: metal (alloy) X and metal (alloy) Y join (welded) at one end. Such pair of wires is then coiled with an electrical insulator and tightly coated in metal jacket welded on the end. The end product looks like a metal wire with one end smooth, and at the other end with two thin wires X and Y led out.
The drawing below shows a typical construction of K-type thermocouple. The sensor is 1mm diameter wide and 300mm long coated in stainless steel jacket. Both ends are shown in magnification, and in the pictures.



The construction of a typical thermocouple sensor

Thermocouple types

The table below compares the most popular types of thermocouples used in industry. The highlighted ones are those used in madur analysers.

Type	Material X	Material Y	µV/K	Min working temp. [°C]	Max working temp. [°C]
E	Chromel	Constantan	60	-200	900
J	Iron	Constantan	51	0	750
T	Copper	Constantan	40	-250	350
K	Chromel	Alumel	40	-200	1250
N	Nicrosil	Nisil	38	-270	1300
S	90% Pt + 10% Rh	Pt	11	0	1400
B	70% Pt + 30% Rh	94% Pt + 6% Rh	8	0	1700
R	87% Pt + 13% Rh	Pt	12	0	1450

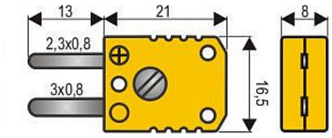
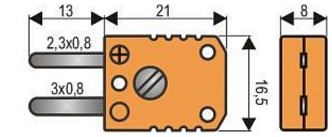
Basic parameters of the most popular thermocouples

As it is presented, the most basic parameters of thermocouple is its sensitivity and the temperature working range

Compensation cables, sockets, connectors

In practice, each thermocouple must be connected to the measuring electric circuit. If this connecting cable is copper then an additional thermocouple joints are created at the contact of copper/metal X and copper/metal Y. Such contacts falsify the results of temperature measurement. To avoid this effect, it is necessary to use a special cables (compensation cables) with wires made of different metals, that are either identical to the metals X and Y of thermocouple or that have the identical thermoelectric characteristics. The same rule applies to sockets, connectors.

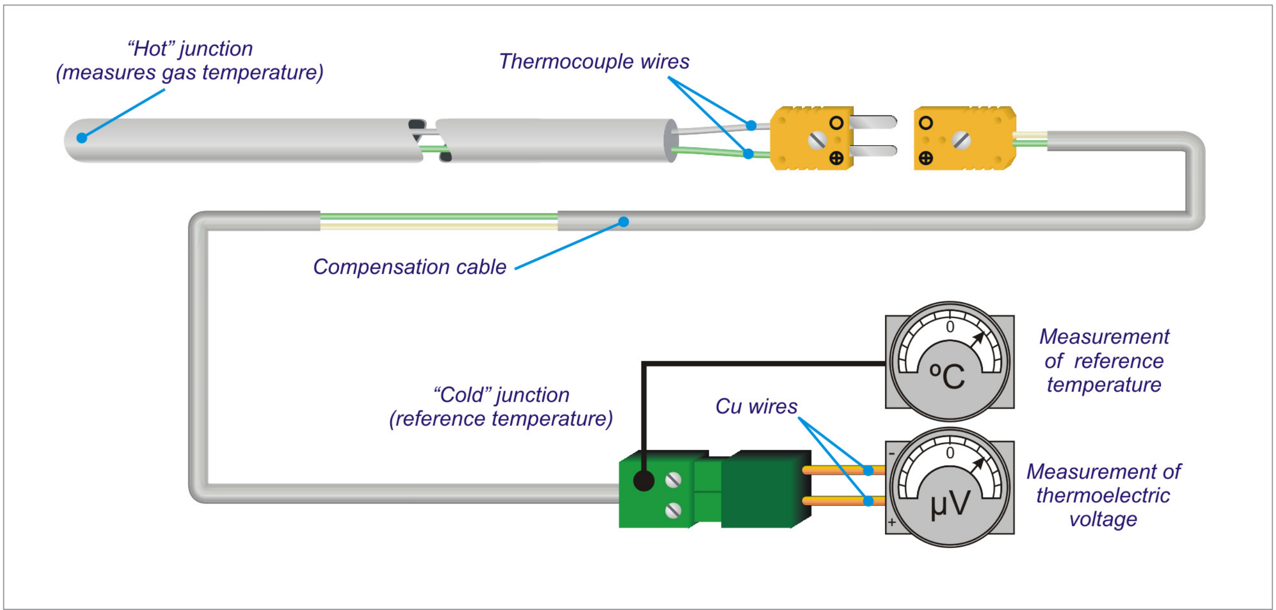
It is possible to acquire appropriate compensation cables, as well as sockets and connectors, for all the available thermocouple types. Each of the cable, socket, connector is colour-coded to ease matching them with suitable thermocouple type. The table below shows the colour-codes for the thermocouple accessories used in madur analysers:

Thermocouple type	Colour of connector	Colours of compensation cable
Type K		
Type S		

Colours of compensation cable and connectors for selected types of thermocouple.

Practical measurement circuit

Drawing below presents how the thermocouple sensor is used in practice. Reference connection is where the compensation cables contact copper wires. It is in fact, two connections, separate for each wire. For the measurement accuracy, it is important to provide an identical temperature for each reference connection.



Temperature measurement with thermocouple in practice

Advantages of thermocouple sensors

- Simple construction.
- Good signal repeatability between different units.
- Small dimensions, and in consequence small inertia and heat capacity.
- Wide range of temperature measurement.
- Reliability and durability.
- Thermocouple generate an active signal (voltage) that allows to work without power supply; and with small impedance, that gives better resistance to electromagnetic noise.
- Low production cost in case of popular thermocouples.

Disadvantages of thermocouple sensors

- Differential principle of operation. Thermocouple measures the difference between the two joints of metals – in order to determine the temperature of the hot junction it is necessary to know the temperature at cold junction.
- Necessity to use special compensation cables.
- Signal's non-linearity.
- Expensive in production in case of noble-metal thermocouples (e.g. made of Platinum-Rhodium Alloy).