CH0302 Process Instrumentation

Lecture 7 – Temperature Measurements

Department of Chemical Engineering
School of Bioengineering
SRM University
Kattankulathur 603203

Introduction – Temperature Measurements Instruments

- Thermal Expansion
- Thermoelectric
- Resistance
- Radiation

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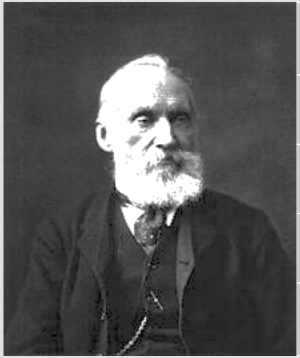
Scientists Contributed to the physics of thermoelectricity

Name	Thomas Johann Seebeck
Born	9 April 1770,
Died	10 December 1831 Berlin
Occupation	Physicist
Known for	Discovering the thermoelectric effect

Scientists Contributed to the physics of thermoelectricity

Name	Jean Charles Athanase Peltier
Born	22 February 1785
Died	27 October 1845 Paris, France
Occupation	Physicist
Known for	Discovering the thermoelectric effect

Scientists Contributed to the physics of thermoelectricity



Name	Sir William Thomson
Born	26 June 1824, Belfast, Ireland
Died	17 December 1907, Scotland
Occupation	Mathematical Physicist
Known for	Joule-Thomson effect

Seebeck Effect

Thomas Johann Seebeck

- Current flows in the thermocouple circuit when the temperatures at the junction are different.

- That is a thermal electro motive force (emf) is generated in the circuit which causes the current flow

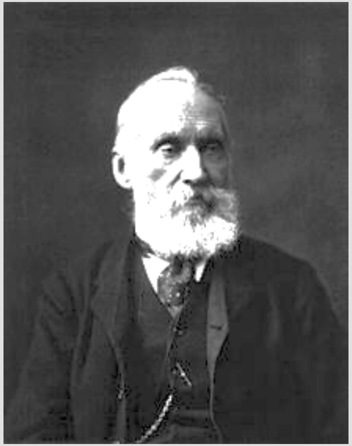
Peltier Effect

Jean Charles Athanase Peltier

- Related the absorption and evolution of heat at the junctions of a thermocouple to the current flow in the circuit.

- That is a the heat is evolved at the reference junction and and absorbed at the measuring junction is in proportion to the flow of current.

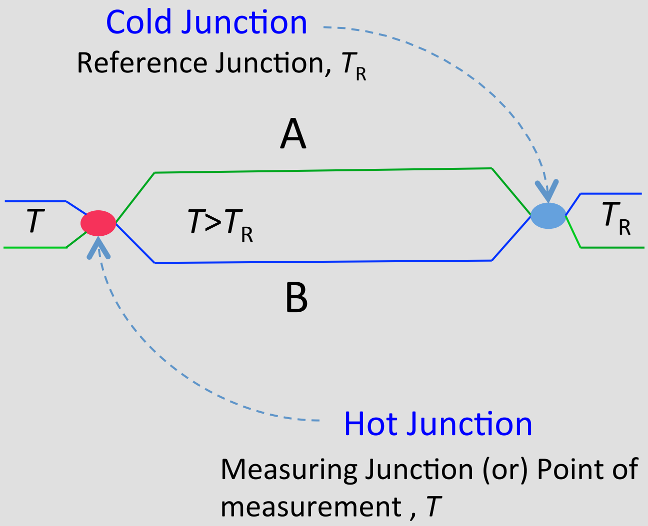
Peltier Effect



Sir William Thomson

- Predicted a relation between the emf generated in a single homogeneous wire and the temperature difference between the ends of the wire.
- That is the emf is propotional to the temperature and the temperature difference in the wires and differs for different metals

Thermocouple circuit

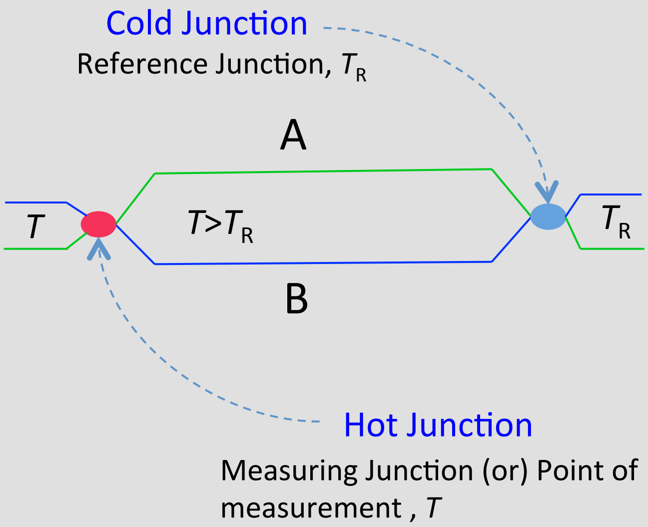


- Thermocouple composed of two dissimilar metals A and B.
- The left hand side junction is the point of measurement (Measurement Junction)
- The right hand side junction is the (Reference Junction). This junction is frequently maintained at either 0^0C (32^0F) or 20^0C (68^0F)

Laws of thermocouple

- Law of homogenous circuits
- Law of intermediate metals
- Law of intermediate temperatures

Laws of homogenous circuits



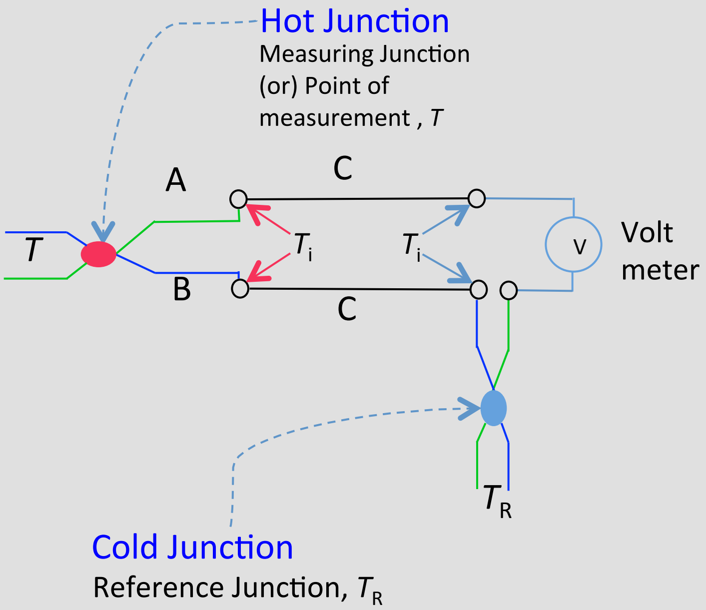
- An electric current cannot be sustained in a circuit of a single homogeneous metal, however varying in section, by the application of heat alone.

- From this law, it is noted that the thermal emf developed in the thermocouple is independent of temperature gradient and its distribution along the wires when measuring junction temperature T is different from the reference junction T_R.

- Therefore the only temperatures related to thermal emf are the measuring junction temperature and the reference junction temperature and all other intermediate temperature are of no consequence.

Thermoelectricity – Thermocouple

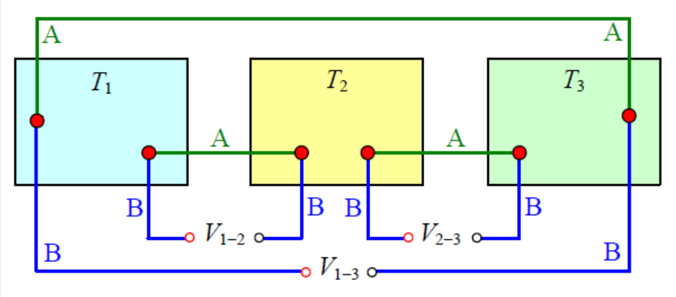
Laws of intermediate metals



– The algebraic sum of thermal emf in a circuit composed of any number of dissimilar metals is zero, if all the circuits are at uniform temperature.

– By combining the law of homogeneous circuits with this law it is possible to insert a measuring device and its connecting wires into the thermocouple circuit at any point without altering the emf, provided that all intermediate junction are at the same temerature T_i as shown in the figure.

Laws of intermediate temperatures



- If identical thermocouples measure the temperature difference between T_1 and T_2, and also between T_2 and $T3$, then the sum of the corresponding voltages $V_{1-2} + V_{2-3}$ must equal the voltage V_{1-3} generated by an identical thermocouple measuring the temperature difference between T_1 and T_3

$$V_{1-3} = V_{1-2} + V_{2-3}$$

Desirable or good Characteristics of thermocouple

- Relatively large thermal emf
- Precision/Accuracy of calibration
- Resistance to corrosion and oxidation
- Linear relation of emf to temperature

Thermoelectricity – Thermocouple

- Relatively large thermal emf

  Thermocouple should have relatively large thermal emf for a given temperature

- Precision/Accuracy of calibration

  Must be capable of calibration to a standard emf temperature relationship and it should maintain without drift

- Resistance to corrosion and oxidation

  Should have high resistance to corrosion in order to have a long life since frequent replacement greatly increases the cost

- Linear relationship

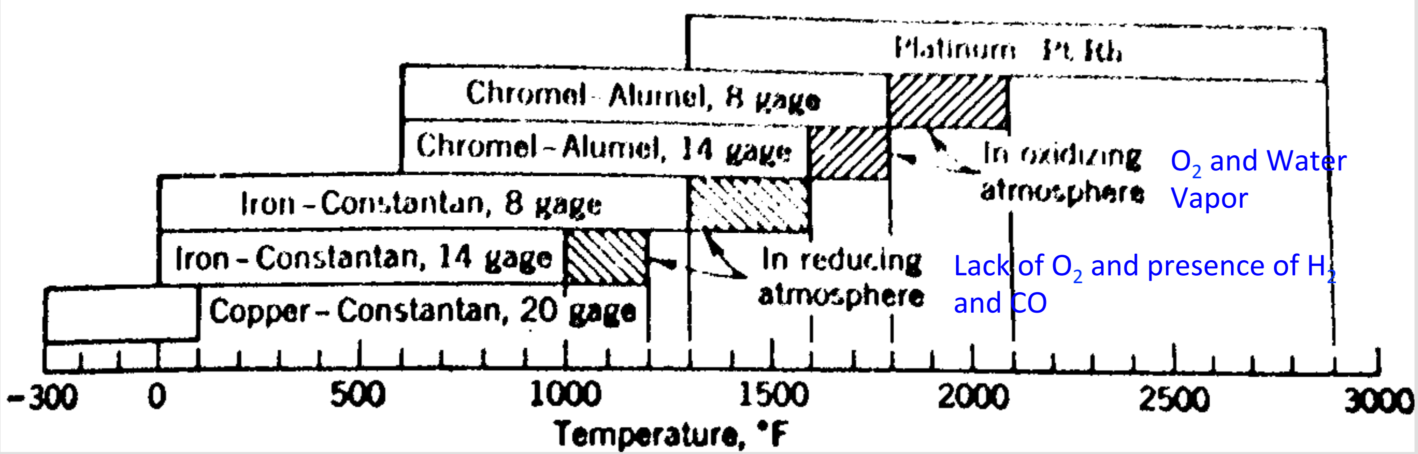
  It is desirable to have a linear relationship between thermal emf and temperature inorder to reduce the problems associated with reference junction temperature

Industrial Thermocouple

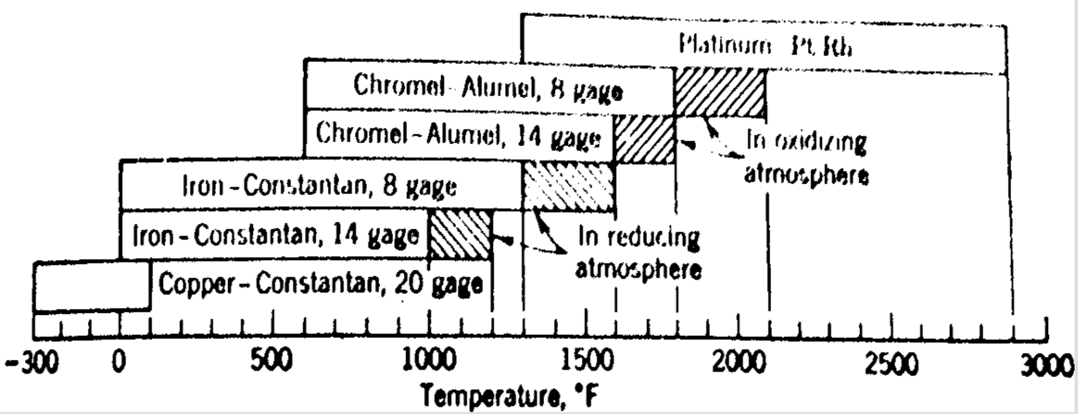
Five commonly used industrial thermocouples

1. Copper - Constantan (55% Cu and 45% Ni)
2. Iron – Constantan
3. Chromel (90% Ni and 10% Cr) – Alumel (95% Nickel, 2% Aluminium, 2% Manganese and 1% Silicon)
4. Platinum – 13% Rhodium
5. Platinum – 10% Rhodium

Industrial Thermocouple



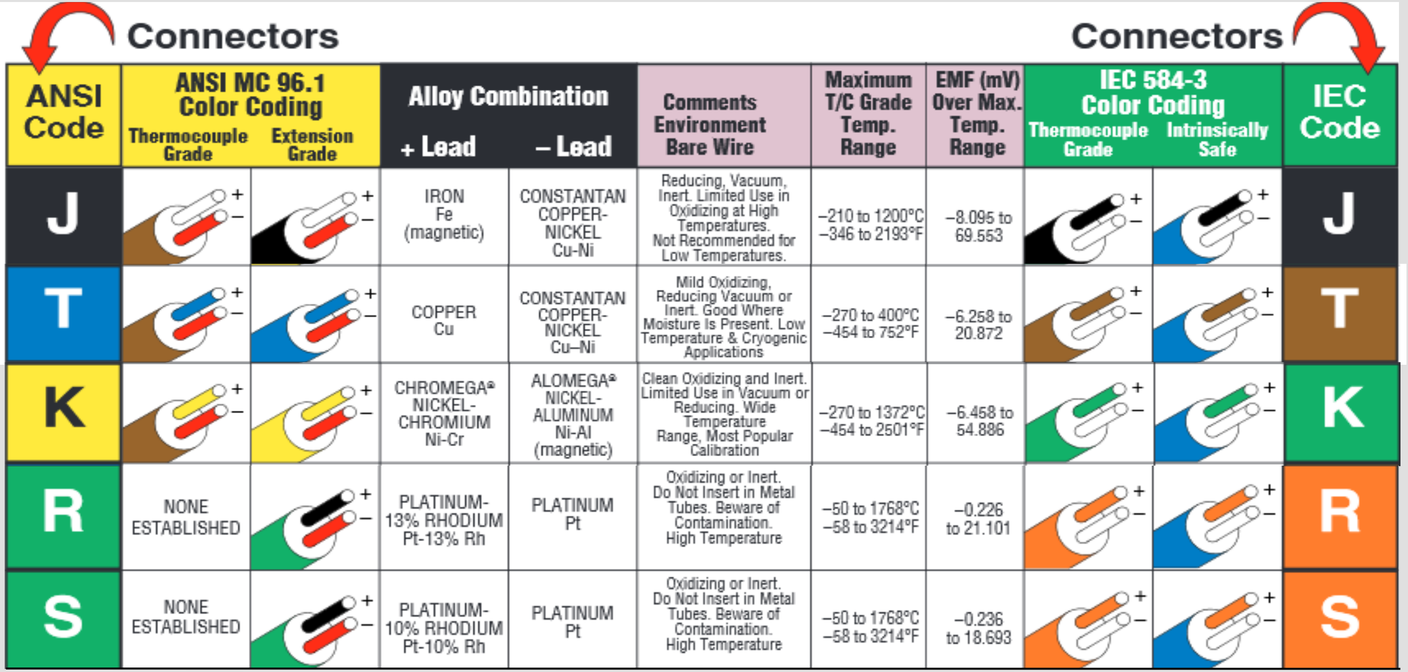
Industrial Thermocouple



American Wire Gauge Standard

AWG	Diameter		Turns of wire, no insulation		Area	
	(in)	(mm)	(per in)	(per cm)	(kcmil)	(mm^2)
0000 (4/0)	**0.4600***	**11.684***	2.17	0.856	212	107
000 (3/0)	0.4096	10.405	2.44	0.961	168	85.0
00 (2/0)	0.3648	9.266	2.74	1.08	133	67.4
0 (1/0)	0.3249	8.251	3.08	1.21	106	53.5
1	0.2893	7.348	3.46	1.36	83.7	42.4
2	0.2576	6.544	3.88	1.53	66.4	33.6
3	0.2294	5.827	4.36	1.72	52.6	26.7
4	0.2043	5.189	4.89	1.93	41.7	21.2
5	0.1819	4.621	5.50	2.16	33.1	16.8
6	0.1620	4.115	6.17	2.43	26.3	13.3
7	0.1443	3.665	6.93	2.73	20.8	10.5
8	0.1285	3.264	7.78	3.06	16.5	8.37
9	0.1144	2.906	8.74	3.44	13.1	6.63
10	0.1019	2.588	9.81	3.86	10.4	5.26

Industrial Thermocouple

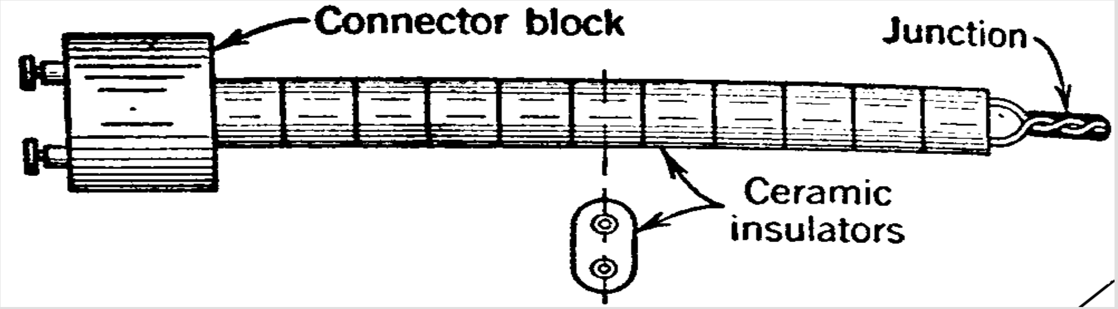


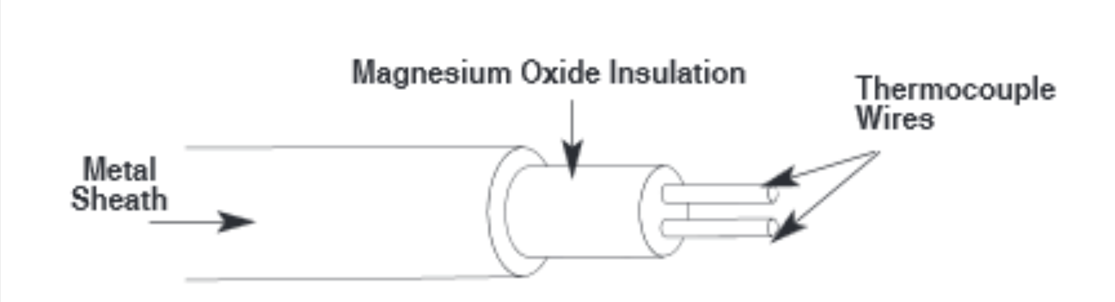
ANSI Code	ANSI MC 96.1 Color Coding: Thermocouple Grade	ANSI MC 96.1 Color Coding: Extension Grade	Alloy Combination: + Lead	Alloy Combination: – Lead	Comments Environment Bare Wire	Maximum T/C Grade Temp. Range	EMF (mV) Over Max. Temp. Range	IEC 584-3 Color Coding: Thermocouple Grade	IEC 584-3 Color Coding: Intrinsically Safe	IEC Code
J			IRON Fe (magnetic)	CONSTANTAN COPPER-NICKEL Cu-Ni	Reducing, Vacuum, Inert. Limited Use in Oxidizing at High Temperatures. Not Recommended for Low Temperatures.	–210 to 1200°C –346 to 2193°F	–8.095 to 69.553			J
T			COPPER Cu	CONSTANTAN COPPER-NICKEL Cu–Ni	Mild Oxidizing, Reducing Vacuum or Inert. Good Where Moisture Is Present. Low Temperature & Cryogenic Applications	–270 to 400°C –454 to 752°F	–6.258 to 20.872			T
K			CHROMEGA® NICKEL-CHROMIUM Ni-Cr	ALOMEGA® NICKEL-ALUMINUM Ni-Al (magnetic)	Clean Oxidizing and Inert. Limited Use in Vacuum or Reducing. Wide Temperature Range, Most Popular Calibration	–270 to 1372°C –454 to 2501°F	–6.458 to 54.886			K
R	NONE ESTABLISHED		PLATINUM-13% RHODIUM Pt-13% Rh	PLATINUM Pt	Oxidizing or Inert. Do Not Insert in Metal Tubes. Beware of Contamination. High Temperature	–50 to 1768°C –58 to 3214°F	–0.226 to 21.101			R
S	NONE ESTABLISHED		PLATINUM-10% RHODIUM Pt-10% Rh	PLATINUM Pt	Oxidizing or Inert. Do Not Insert in Metal Tubes. Beware of Contamination. High Temperature	–50 to 1768°C –58 to 3214°F	–0.236 to 18.693			S

http://www.omega.com/temperature/pdf/tc_colorcodes.pdf

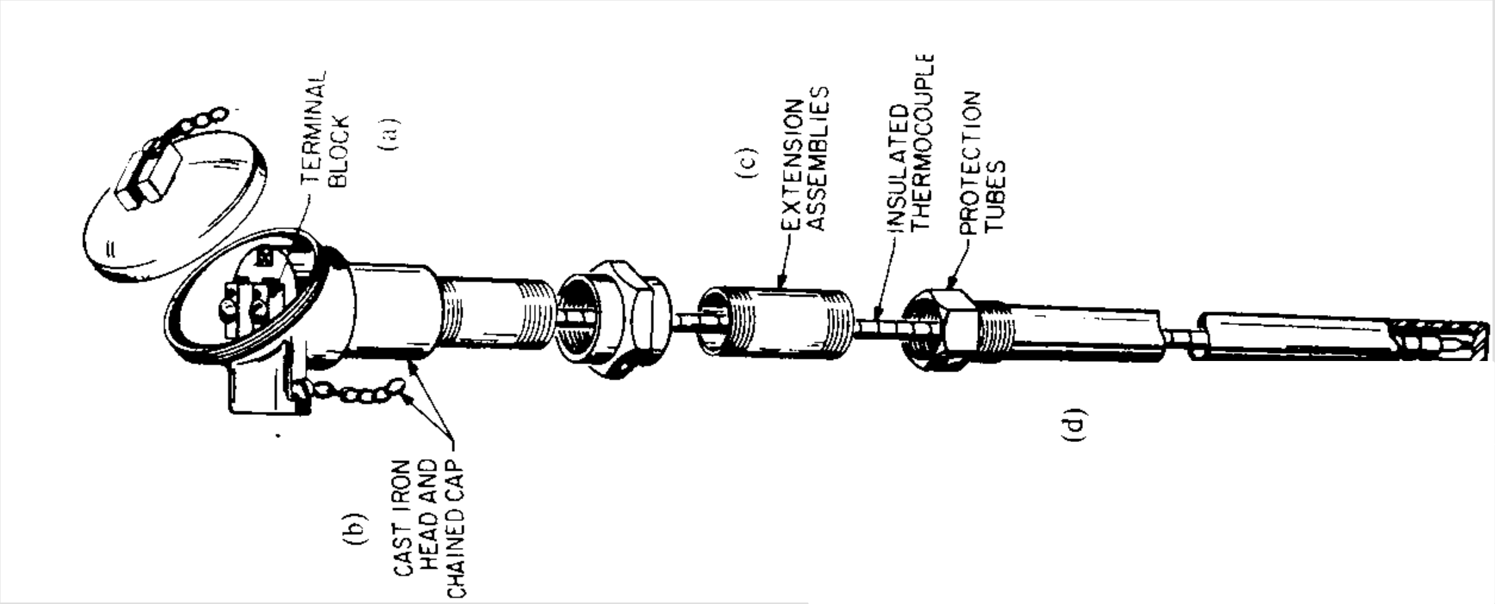
Industrial Thermocouple

Thermocouple and Junction Assembly

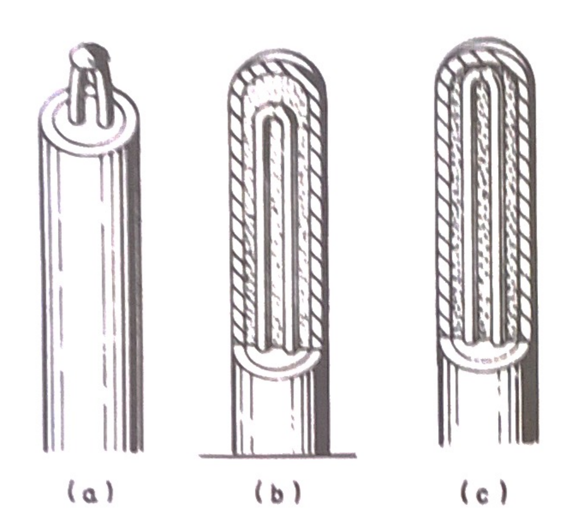




Industrial Thermocouples



Industrial Thermocouple - Junction

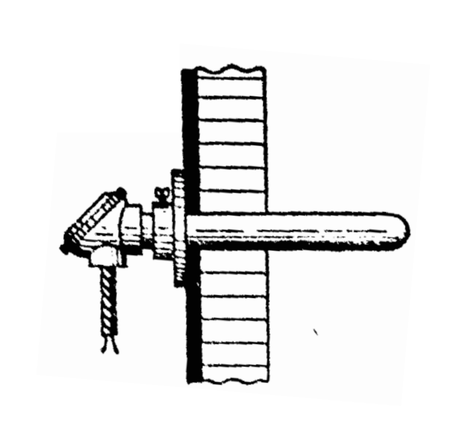


(a) Exposed Junction

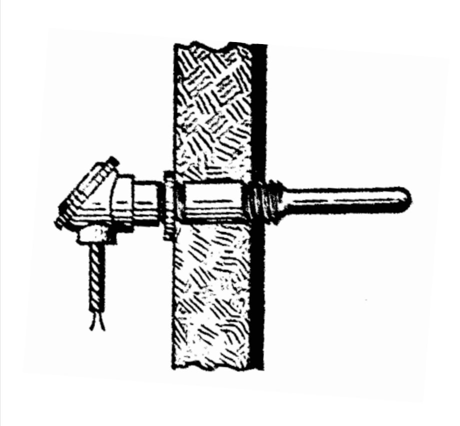
(b) Unground junction

(c) Ground Junction

Thermocouple – Thermal Well Installation

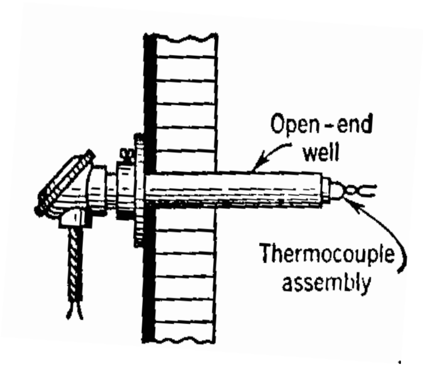


Open end with ground Junction

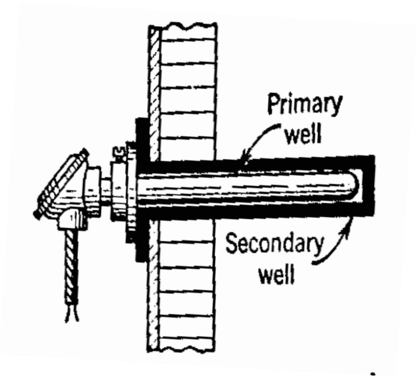


Open end with screw flange ungrounded junction

Thermocouple – Thermal Well



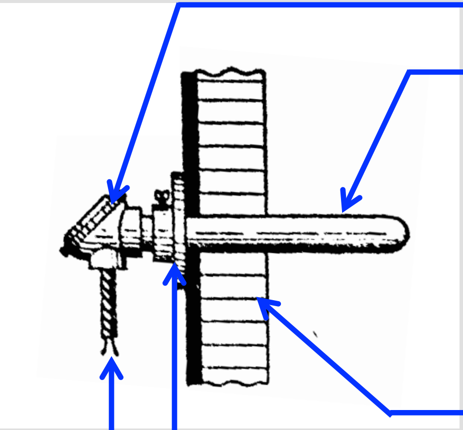
Open end with flange
with exposed junction



Open end with 1^0 and
2^0 grounded junctions

Thermocouple – Thermal Well Assembly

Open end with ground Junction



Terminal block connected to head

Thermal Well (Exposed to measuring Medium)

Used for measurement of air or gas in furnace

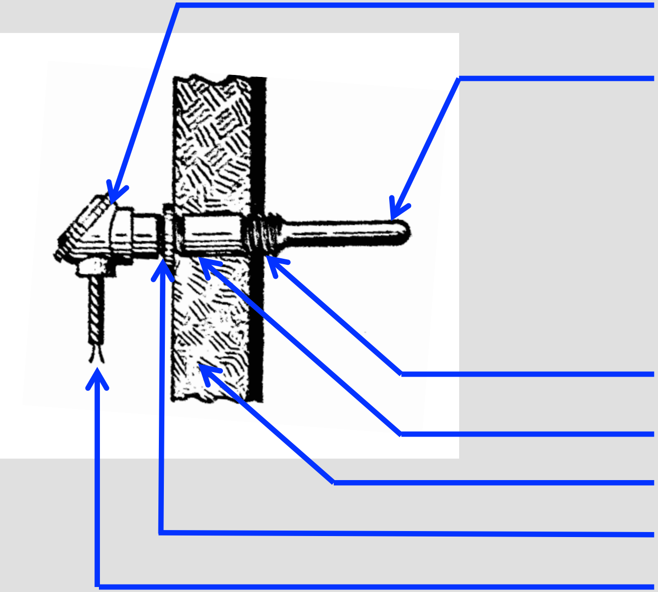
Insulated wall

Flange

Thermocouple conductors

Thermocouple – Thermal Well Assembly

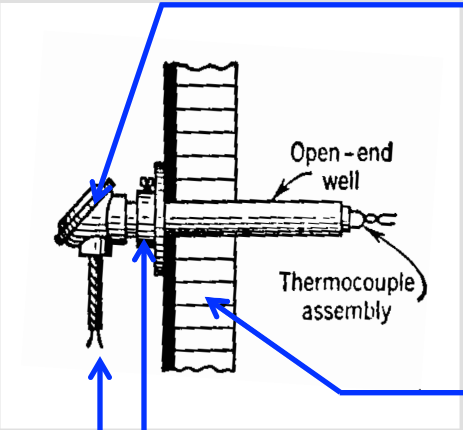
Open end with screw flange ungrounded junction



Used for pressure vessels and pipelines particularly for liquid under pressure

Thermocouple – Thermal Well Assembly

Open end with flange with exposed junction



Terminal block connected to head

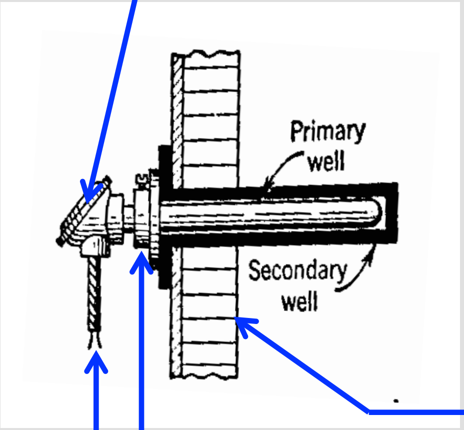
- Used when only slight protection is required (furnace in low temperatures)
- It only protects thermocouple from mechanical damage and erosive effect

Insulated wall

Flange

Thermocouple conductors

Thermocouple – Thermal Well Assembly



Terminal block connected to head

- Over 2000 ^{0}F where corrosion is expected, primary and secondary thermo wells are employed

- Primary well serves as a protective tube

- Secondary well has three purposes:
  (I) acts as a cover to primary well
  (ii) prevents sagging of assembly at high temperatures
and (iii) prevents gas leakage

Insulated wall

Flange

Thermocouple conductors

Open end with 1^{0} and 2^{0} grounded junctions

Mechanical properties that must be considered in the selection of thermal well

- Resistance to corrosion and oxidation
- Resistance to mechanical shock
- Resistance to thermal shock
- Resistance to gas leakage
- Overall good mechanical strength

References

1. Donald P. Eckman, (2004) *Industrial Instrumentation*, CBS Publishers, Pp. 1- 27.
2. https://www.mne.psu.edu/me345/Lectures/Temperature_measurement.pdf
3. www.wikipedia.com

Thank You