Instrumentation & Measurement

Temperature Measurement

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Temperature Concept and measurement

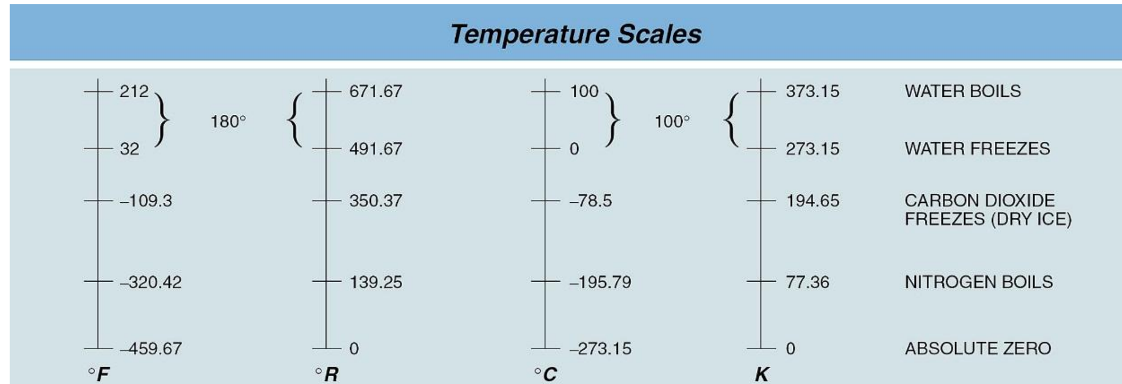
- What is Temperature
- Temperature units of measurement
- Heat Transfer types

What is Temperature

- Temperature is an indirect measurement of the heat energy contained in molecules.
- When molecules have a low level of energy they are cold, and as energy increases they get warmer.
- The energy is in the form of molecular movement or vibration of the molecules.
- Absolute zero is the lowest temperature possible, where there is no molecular movement and the energy is at a minimum. Absolute zero is a theoretical state and cannot actually be reached. This condition is the zero point for the absolute temperature scales.

Temperature measurement units

The four common temperature scales are the **Fahrenheit, Rankine, Celsius, and Kelvin scales.**



Temperature Conversions

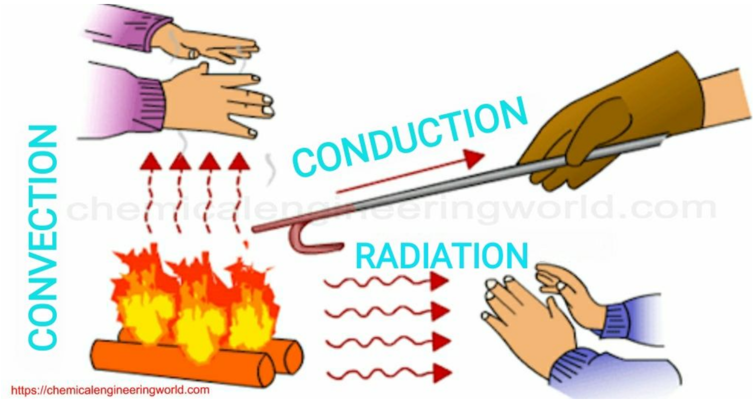
	°F	°R	°C	K
°F	—	°R = °F + 459.67	°C = $5/9$ × (°F – 32)	K = $5/9$ × (°F + 459.67)
°R	°F = °R – 459.67	—	°C = ($5/9$ × °R) – 273.15	K = $5/9$ × °R
°C	°F = ($9/5$ × °C) + 32	°R = $9/5$ × (°C + 273.15)	—	K = °C + 273.15
K	°F = ($9/5$ × K) – 459.67	°R = $9/5$ × K	°C = K – 273.15	—

Heat Transfer

Heat transfer is the movement of thermal energy from one place to another.

Three Heat Transfer types:

- **Conduction** is heat transfer that occurs the heat is passed from molecule to molecule through the material.
- **Convection** is heat transfer by the movement of gas or liquid from one place to another caused by a pressure difference.
- **Radiation** is heat transfer by electromagnetic waves emitted by a higher-temperature object and absorbed by a lower-temperature object.

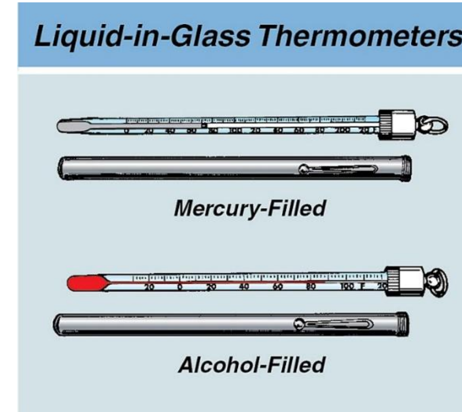


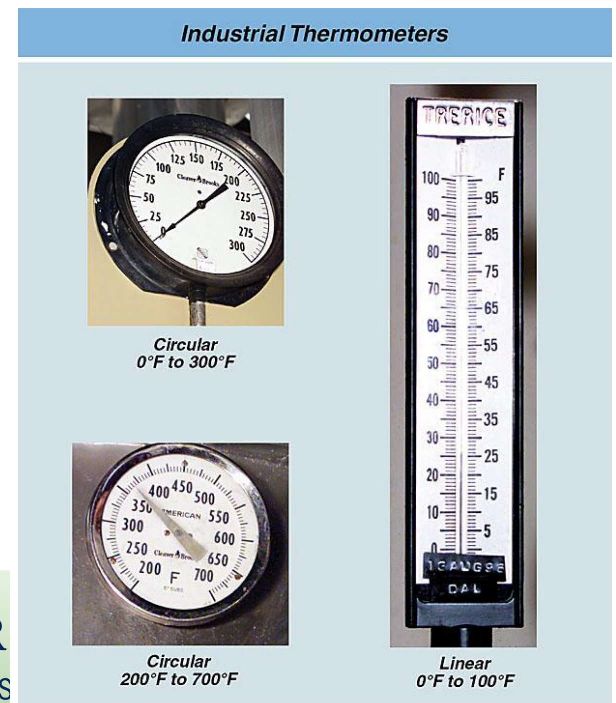
Thermometer

- Thermal expansion Thermometer
  - Liquid-in-Glass Thermometers
  - Bimetallic Thermometers
  - Pressure-Spring Thermometers
- Electrical Thermometer
  - RTD
  - Thermistor
  - Thermocouple
  - Infrared Radiation Thermometer

Liquid-in-Glass Thermometers

- The different materials expands and contract with heat energy with different rate. The material expansion is used to measure temperature.
- The volumetric expansion of liquids is typically many times greater than that of glass. Since the volume of the liquid changes more than the change in the glass, the liquid moves up or down in the tube with changes in temperature.





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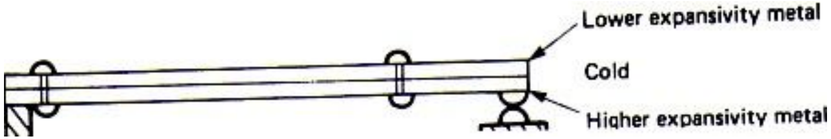
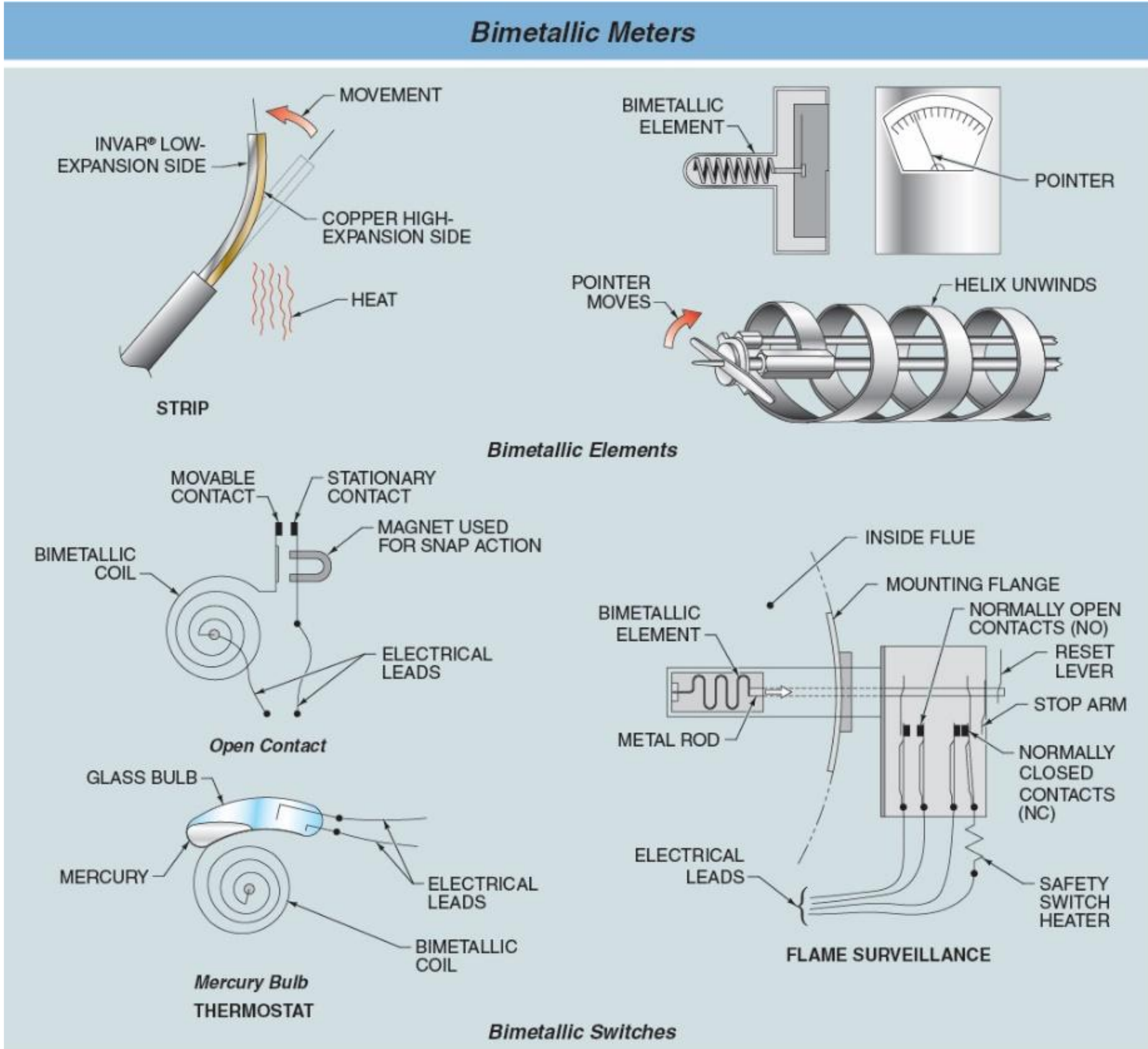
Bimetallic Thermometers

https://youtu.be/6r9UAdb2kDo

Bimetallic Temperature Switch



A **bimetallic sensor** is a thermal expansion sensor that uses a strip consisting of two metal alloys with different coefficients of thermal expansion that are fused together and formed into a single strip and a pointer or indicating mechanism calibrated for temperature reading.



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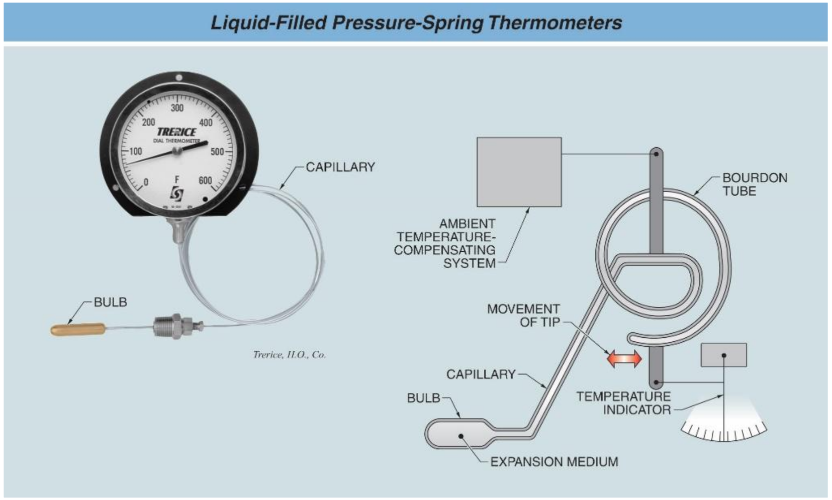
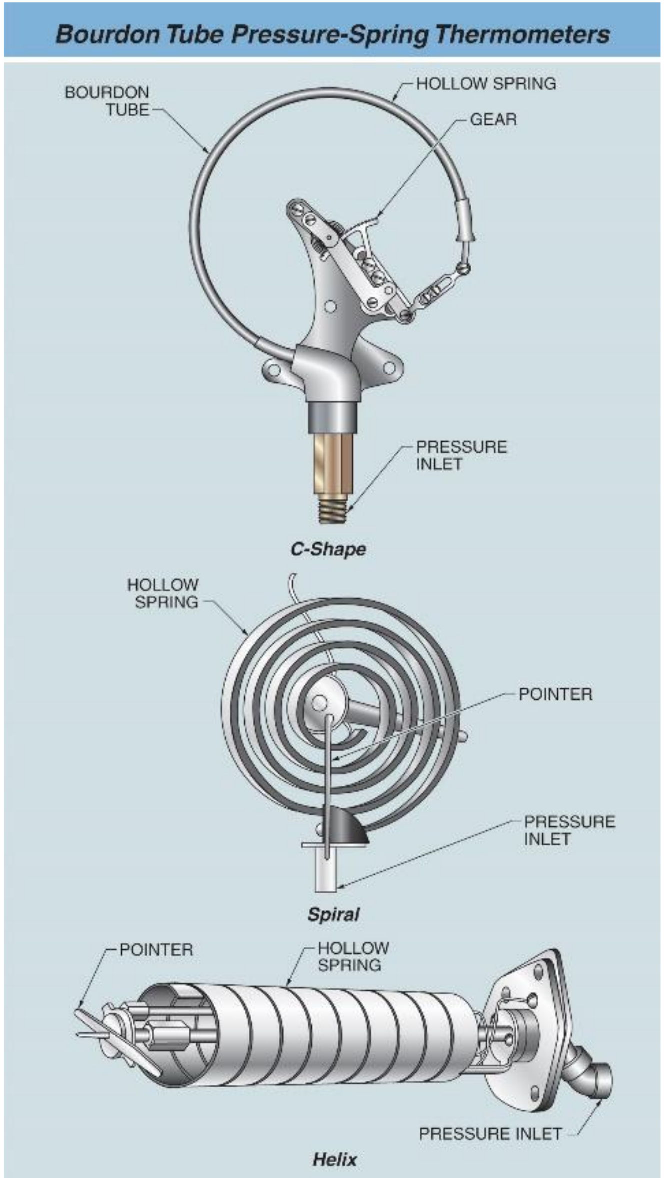
Pressure-Spring Thermometers

A pressure-spring thermometer is a thermal expansion thermometer consisting of a filled, hollow spring attached to a capillary tube and bulb where the fluid in the bulb expands or contracts with temperature changes.





Thermometer

- Thermal expansion Thermometer
  - Liquid-in-Glass Thermometers
  - Bimetallic Thermometers
  - Pressure-Spring Thermometers
- Electrical Thermometer
  - RTD
  - Thermistor
  - Thermocouple
  - Infrared Radiation Thermometer

RTD (Resistance Temperature Detector)

Temperature effect on Resistance of metal

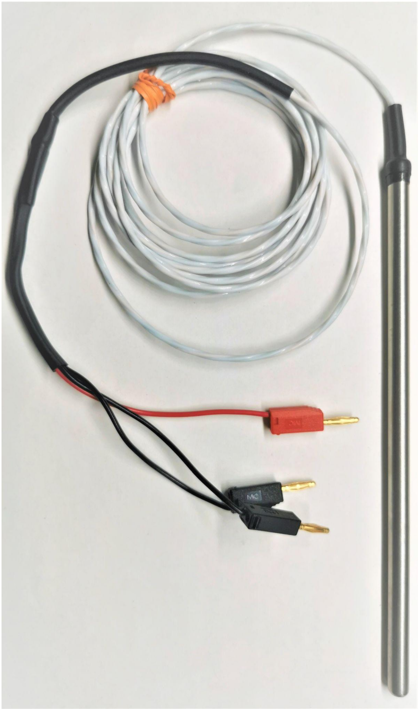
In linear area

$$R_T = R_{T0}(1 + \alpha \times \Delta T)$$

$$\Delta T = T - T_0 \rightarrow Temperature\, changes\, from\, T_0 \rightarrow T$$
$$R_T \rightarrow Temperature\ at\, T$$
$$R_{T0} \rightarrow Temperature\ at\, T_0$$

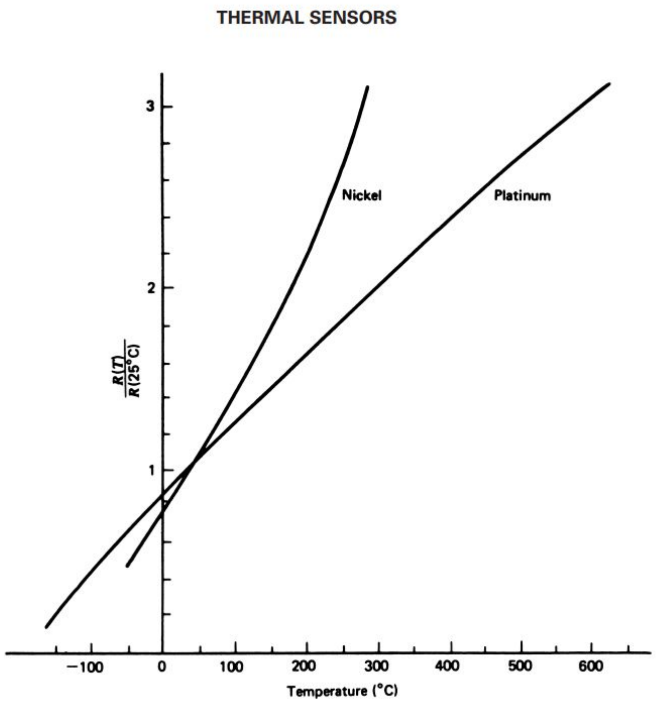
$$\alpha \rightarrow Temperature\, cof\, fiecient\, of\, resis\tan ce$$

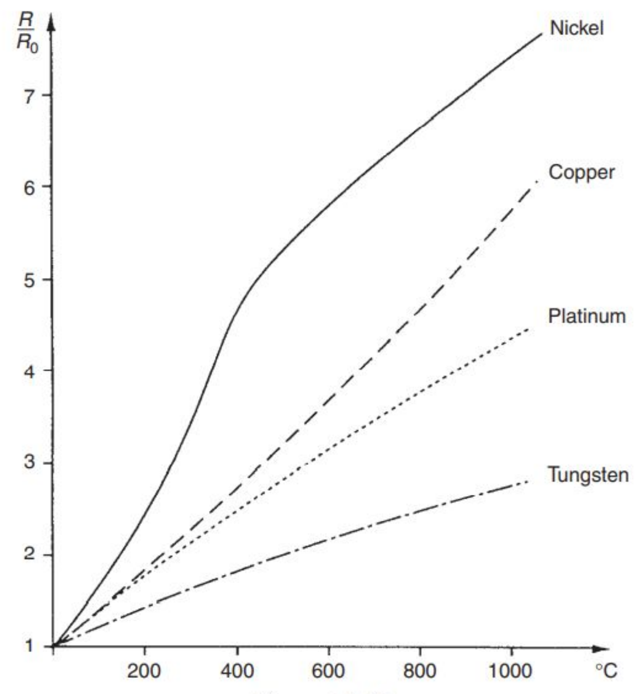
$$Sensitivity = \frac{\Delta Output}{\Delta Input} = \frac{\Delta R}{\Delta T} = R_0 \times \alpha$$



RTD (Resistance Temperature Detector)

- **Platinum is very repeatable and linear temperature to resistance correlation**





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RTD : Measurement Range

- **Platinum has the widest useful temperature range**

Platinum: −270°C to +1000°C (although use above 650°C is uncommon)
Copper: −200°C to +260°C
Nickel: −200°C to +430°C

Tungsten: −270°C to +1100°C
Carbon: −273°C to −173°C

RTD : PT-100 & PT-1000 Platinum RTD

- PT stands for platinum and 100 means that the resistance at 0 ℃ is equal to 100 Ω and for the PT-1000 the resistance at 0 ℃ is equal to 1000 Ω.
- Platinum has the most linear resistance-temperature characteristic
- It also has good chemical inertness (Resistive to corrosion), It is therefore far more common than copper or nickel RTDs
- Platinum temperature coefficient (α) = 0.00385 per ℃

Properties of PT-1000 :

- higher measurement sensitivity
- the resistance of connecting leads has less effect on measurement accuracy.
- However, cost goes up as the nominal resistance increases.

Examples

Examples:

$$R_T = R_{T0}(1 + \alpha \times \Delta T)$$

Platinum Temperature Coefficient = 0.00385

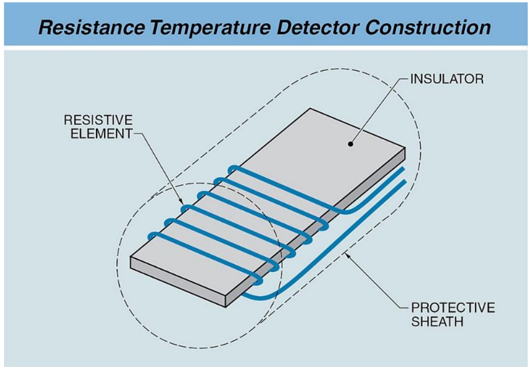
Example 1: How much does a resistance of PT-100 increases if its temperature raises 1 °C?

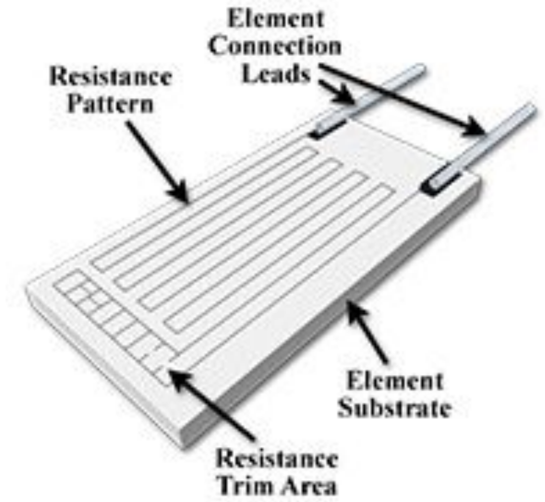
Example 2: How much does a resistance of PT-1000 increases if its temperature raises 1 °C?

Example 3: Inside a tank there is PT-100. If we measure resistance of a PT-100 it shows 119.25 Ω

RTD Construct

- Platinum thermometers are made in three forms:
  - as a film deposited on a ceramic substrate,
  - as a coil mounted inside a glass
  - ceramic probe

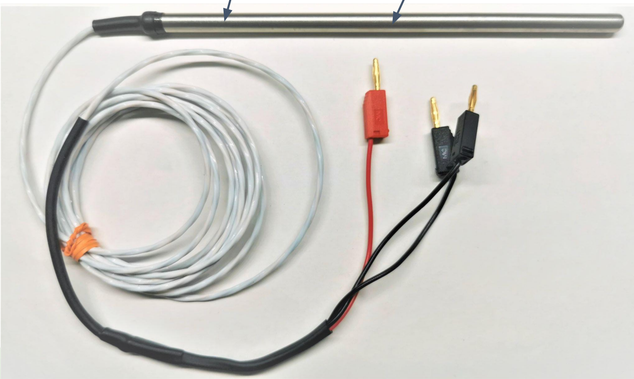


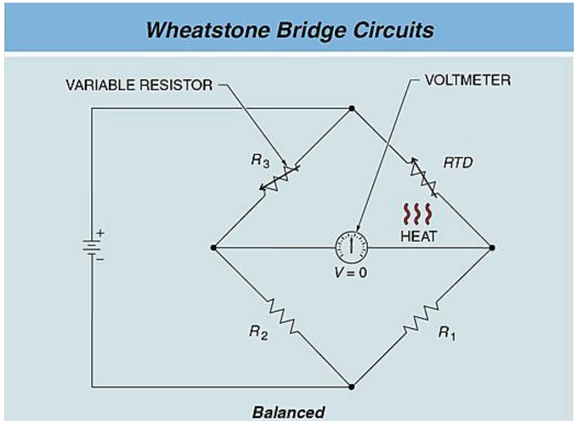


[RTD (dwyer-inst.com)](https://www.dwyer-inst.com)

Protective Sheath stainless steel 316 or 304 resistive to corrosion

Resistance Wire (Inside)





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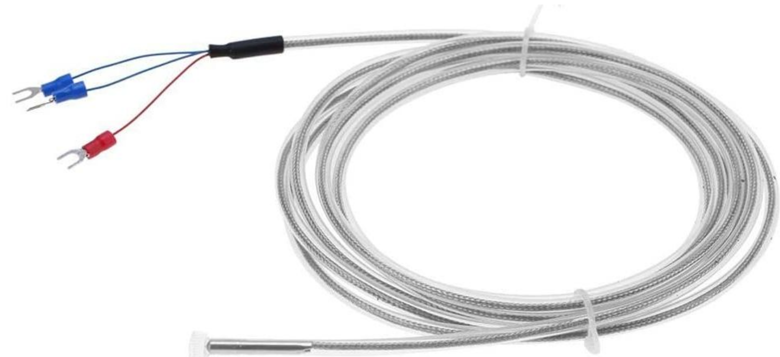
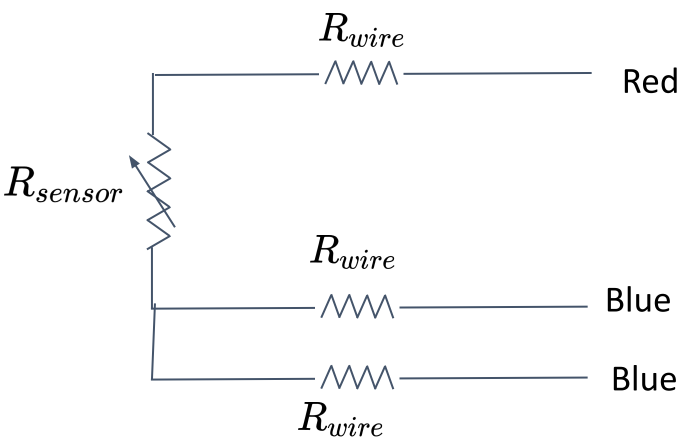
Wiring

- To eliminate the connecting wiring resistance effect, 3 wires are used.





$$R_{Red-Blue} = R_{wire} + \boxed{R_{sensor}} + R_{wire}$$

$$R_{Blue-Blue} = R_{wire} + R_{wire}$$

$$\boxed{\overbrace{R_{sensor} = R_{Red-Blue} - R_{Blue-Blue}}}$$

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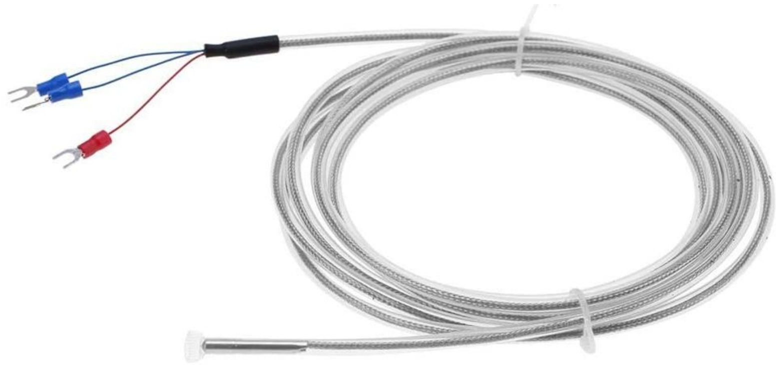
Example



In front picture this is a PT-100.

The resistance between red and blue wire is 114.1 Ω and the resistance between blue and blue is 1.5 Ω. What is the temperature sensed by sensor?

$$R_T = R_{T0}(1 + \alpha \times \Delta T)$$

Platinum Temperature Coefficient = 0.00385

$R_{sensor} = 114.1\text{-}1.5{=}112.6$

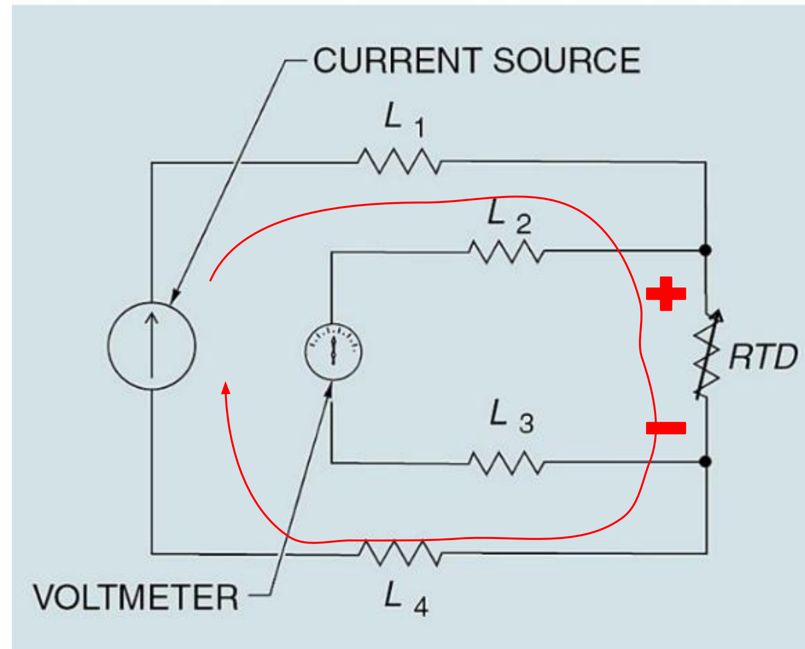
$112.6 = 100 \times (1 + 0.00385 \times (T - 0))$
$\Rightarrow T = 32.72\,^{\circ}C$

In a 4-wire RTD, the sensing RTD takes the place of two resistors in the Wheatstone bridge.

In a 4-wire RTD, the sensing RTD takes the place of two resistors in the Wheatstone bridge. The voltage that normally connects to the top and bottom of the bridge is carried directly to the sensing RTD. Therefore, no current is routed through the RTD sensing wires. There is no need to compensate for wire resistance as with the 3-wire RTD circuit.

3 wires modifies the connecting wire resistance effect. The 4 wire cancel the effect.

Four-Wire RTD



Thermistor

- Thermistor are made of semiconductor
- It is nonlinear sensor
- It is small and response time short

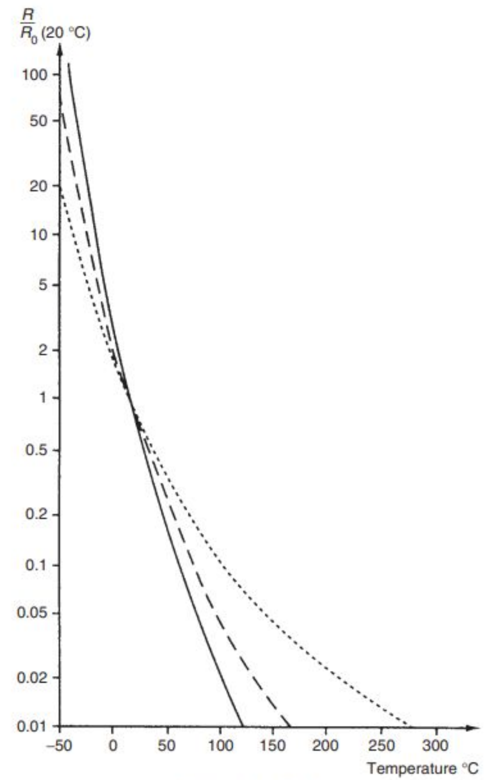


Figure 14.12

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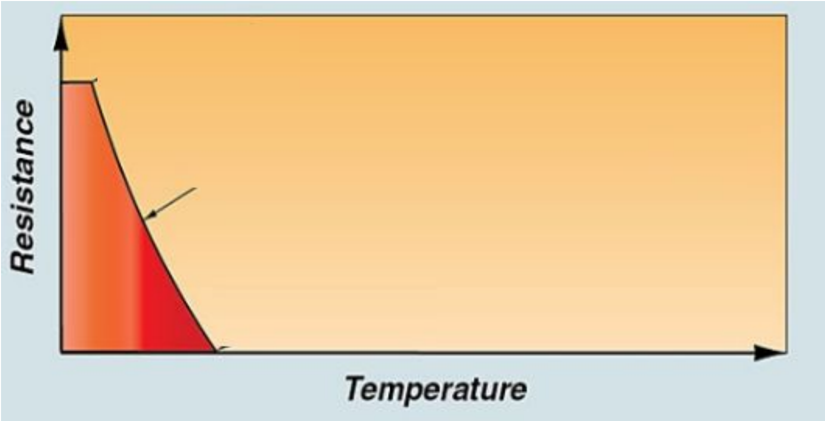
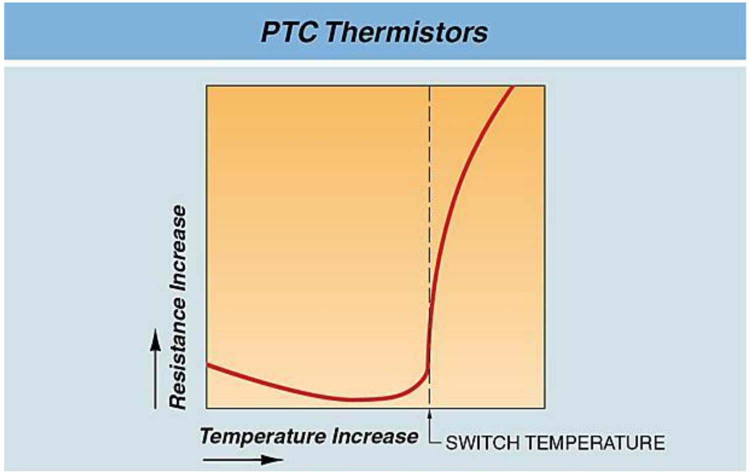
NTC & PTC

NTC thermistors have a resistance that decreases with increases in temperature.



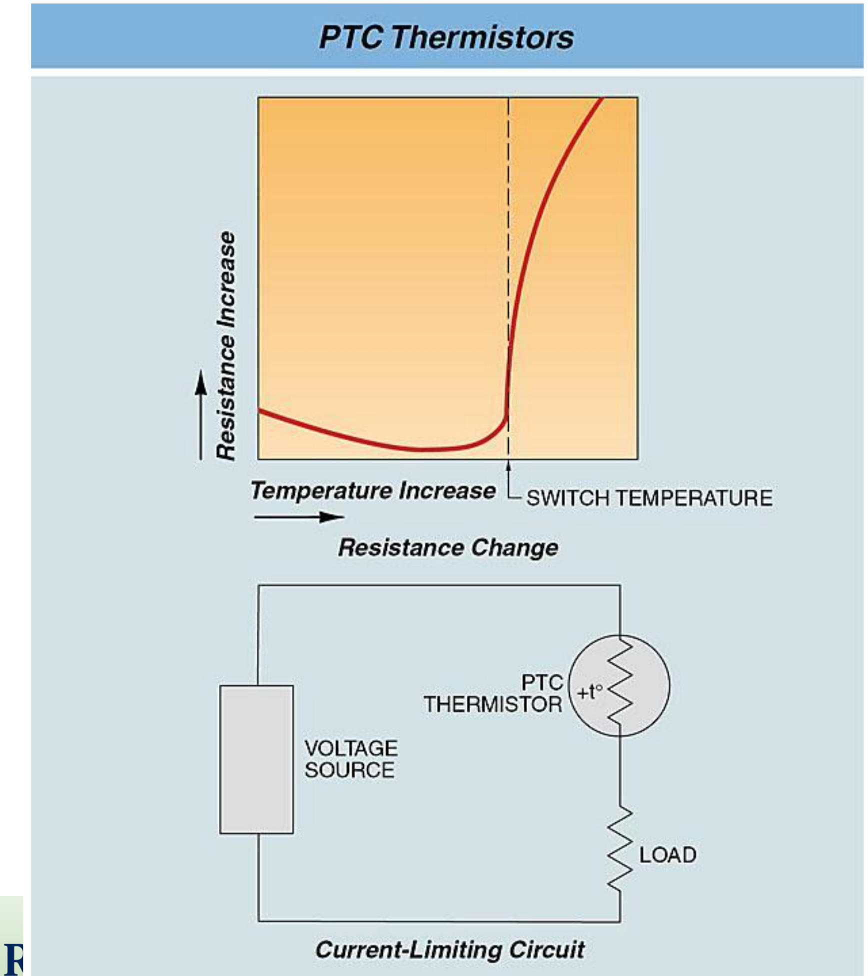
PTC thermistors have a resistance that increases with increases in temperature.



PTC Application

The increase in resistance of a PTC thermistor at the switch temperature makes it suitable for current-limiting applications.

For currents lower than the limiting current, the power generated in the unit is insufficient to heat the PTC thermistor to its switch temperature. However, as the current increases to the critical level, the resistance of the PTC thermistor increases at a rapid rate so that any further increase in power dissipation results in a current reduction.

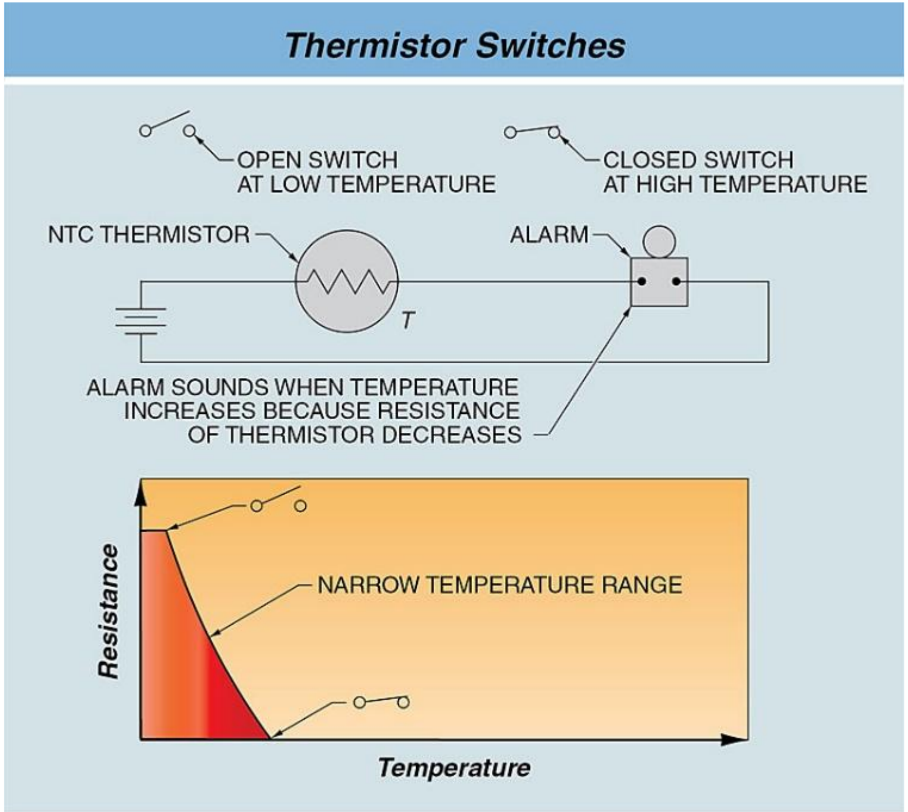


NTC Application

NTC thermistors are well suited for many applications that require a large change in resistance when a small change of temperature occurs.

For example, a thermistor can be used to sound an alarm if the temperature increases above a setpoint.

As the temperature increases, the resistance of the thermistor decreases. As the resistance of the thermistor decreases, the current flow increases and there is a larger voltage drop across the alarm. The alarm sounds as long as the temperature is high.



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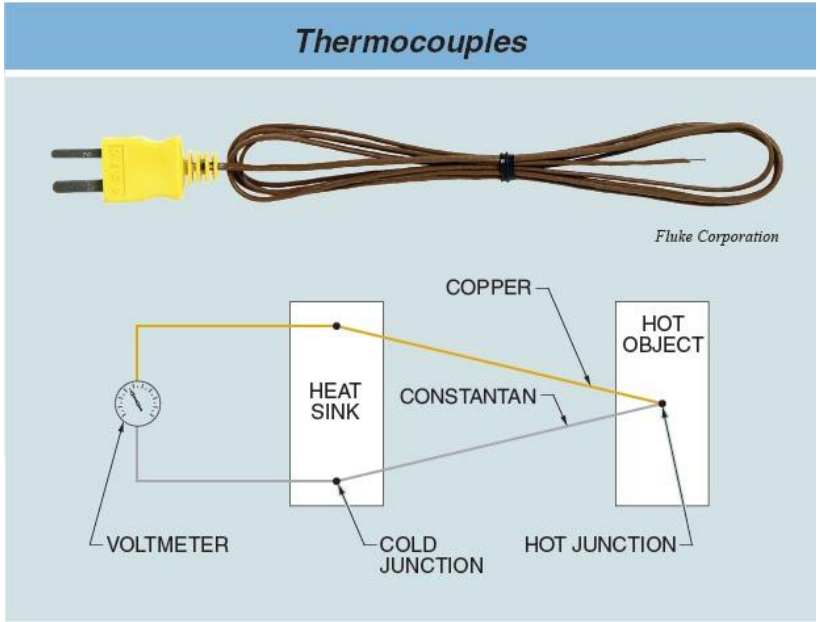
Thermocouple

A **thermocouple** is an electrical thermometer consisting of two dissimilar metal wires joined at one end and a voltmeter to measure the voltage at the other end of the two wires.



$$V \,\alpha\, \Delta T$$

$$\Delta T = T_{hot\ junction} - T_{Cold\ junction}$$

Thermocouple measure differential temperature

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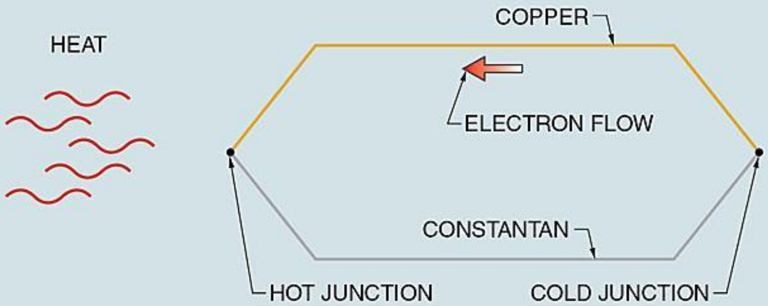
The **Seebeck effect** is a thermoelectric effect where continuous current is generated in a circuit where the junctions of two dissimilar conductive materials are kept at different temperatures.

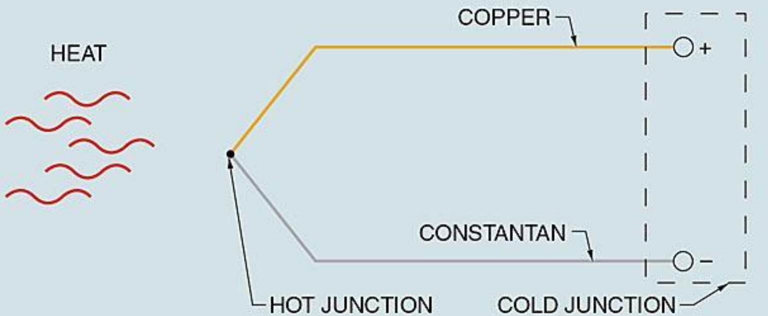
When the circuit is opened at the cold junction, an electrical potential difference (the Seebeck voltage) exists across the two dissimilar wires at that junction.

The voltage produced by exposing the measuring junction to heat depends on the composition of the two wires and the temperature difference between the hot junction and the cold junction.

Seebeck Effect



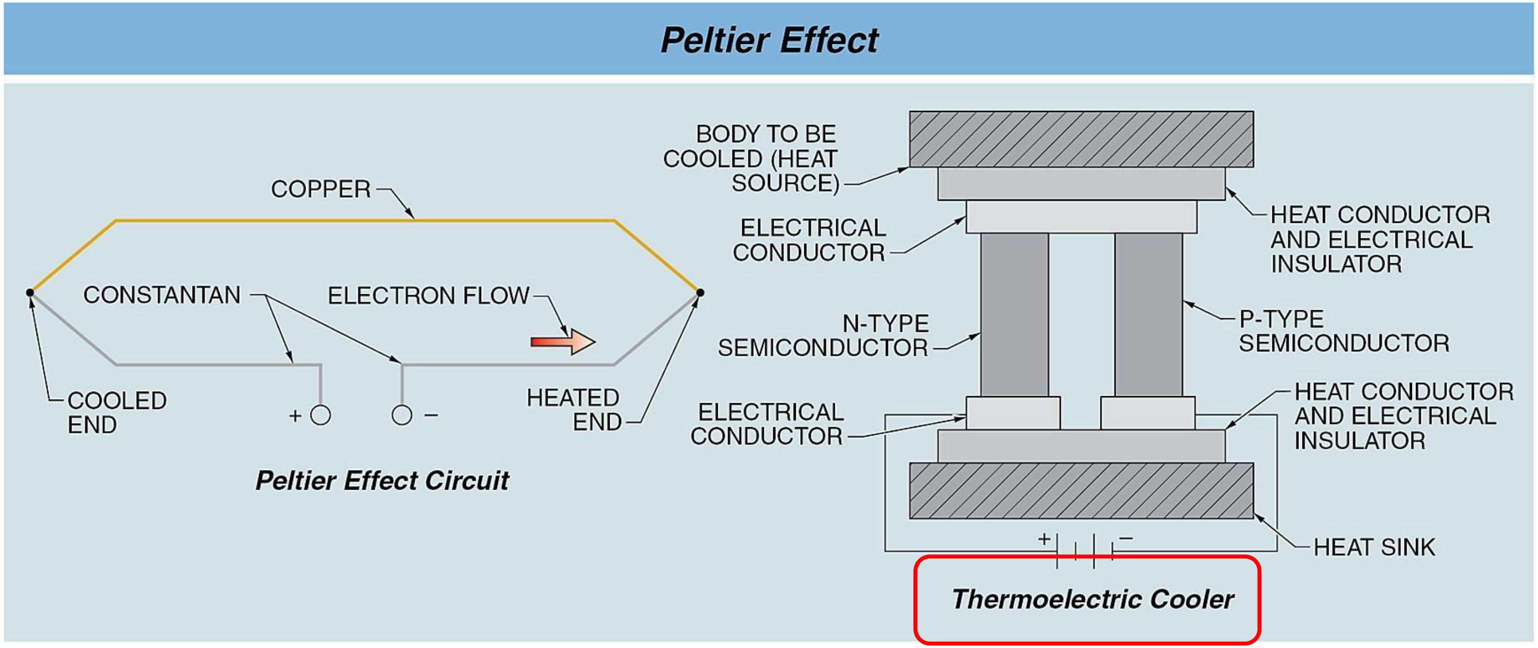
Seebeck Effect



Seebeck Voltage

The **Peltier effect** is a thermoelectric effect where heating and cooling occurs at the junctions of two dissimilar conductive materials when a current flows through the junctions.

It is not the same as resistance heating of wires caused by current flow. The Peltier effect only occurs at the junctions of dissimilar materials



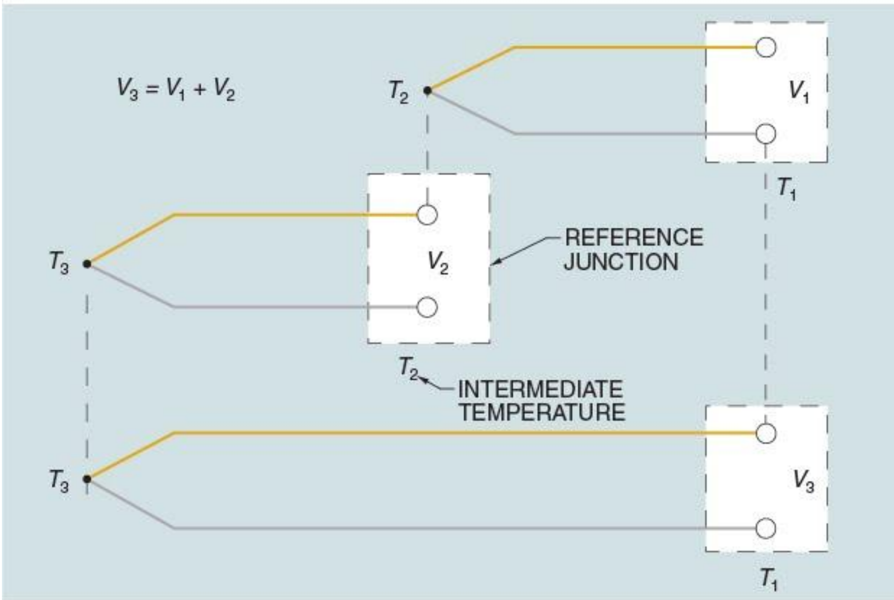
The **law of intermediate temperatures** states that the temperature at the end of the wires determines the electrical potential regardless of the intermediate temperatures.

$$V_1 \,\alpha\, T_2 - T_1$$
$$V_2 \,\alpha\, T_3 - T_2$$
$$\Downarrow$$
$$V_1 + V_2 \;\alpha\; T_3 - T_1$$

$$V_3 \;\alpha\; T_3 - T_1$$

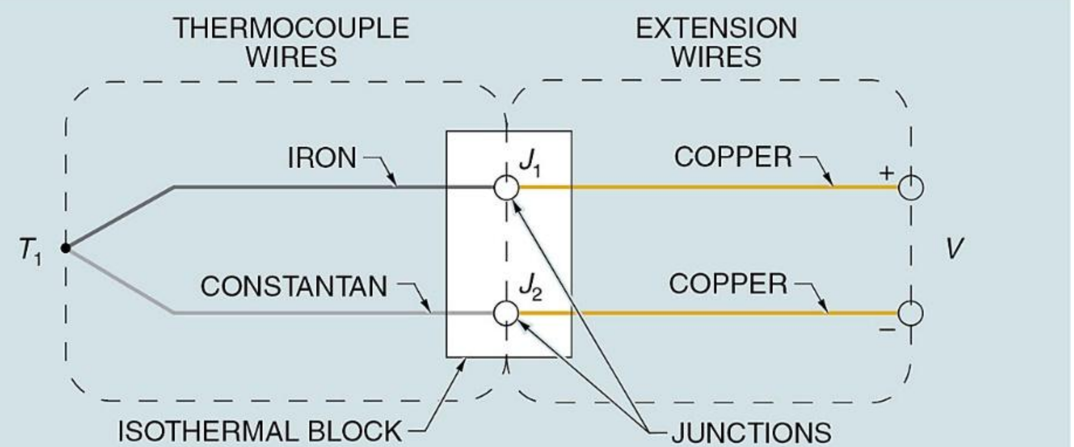
A temperature-sensitive resistor, or thermistor, is used to measure the reference temperature and an adjustment is made to the measured voltage to determine the temperature at the measured junction.

Law of Intermediate Temperatures



The ***law of intermediate metals*** is a law stating that the use of a third metal in a thermocouple circuit does not affect the voltage, as long as the temperature of the three metals at the point of junction is the same.

Law of Intermediate Metals



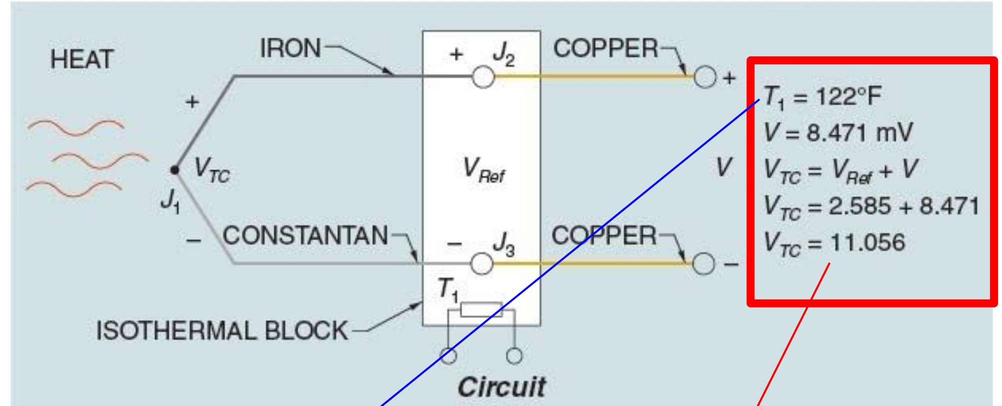
WHEN TEMPERATURES OF JUNCTIONS J_1 AND J_2 ARE EQUAL, THE CIRCUIT CAN BE USED TO MEASURE TEMPERATURE T_1

Cold junction compensation is the process of using automatic compensation to calculate temperatures and is often achieved by measuring the temperature of the cold junction with a thermistor.

The voltmeter junctions are wired to an isothermal (constant temperature) block. Cold junction compensation measures the temperature of the isothermal block and calculates the equivalent reference voltage

$$V_{TC} \,\alpha\, T_{Hot\ Junction} - T_{Cold\ Junction}$$
$$= T_{J1} - T_1$$

Thermocouple Voltage with Isothermal Block



Thermoelectric Voltage in mV

°C	0	1	2	3	4	5	6	7	8	9
40	2.059	2.111	2.164	2.216	2.269	2.322	2.374	2.427	2.480	2.532
50	2.585	2.638	2.691	2.744	2.797	2.850	2.903	2.956	3.009	3.062
60	3.116	3.169	3.222	3.275	3.329	3.382	3.436	3.489	3.543	3.596
190	10.224	10.279	10.335	10.390	10.446	10.501	10.557	10.612	10.668	10.723
200	10.779	10.834	10.890	10.945	11.001	11.056	11.112	11.167	11.223	11.278
210	11.334	11.389	11.4445	11.501	11.556	11.612	11.667	11.723	11.778	11.834

Thermocouple Voltage Table

T=205 C

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Thermocouples are often used in situations where the RTD devices are not appropriate because of **high temperatures** or **a corrosive measuring environment**.

A modern digital thermocouple includes a

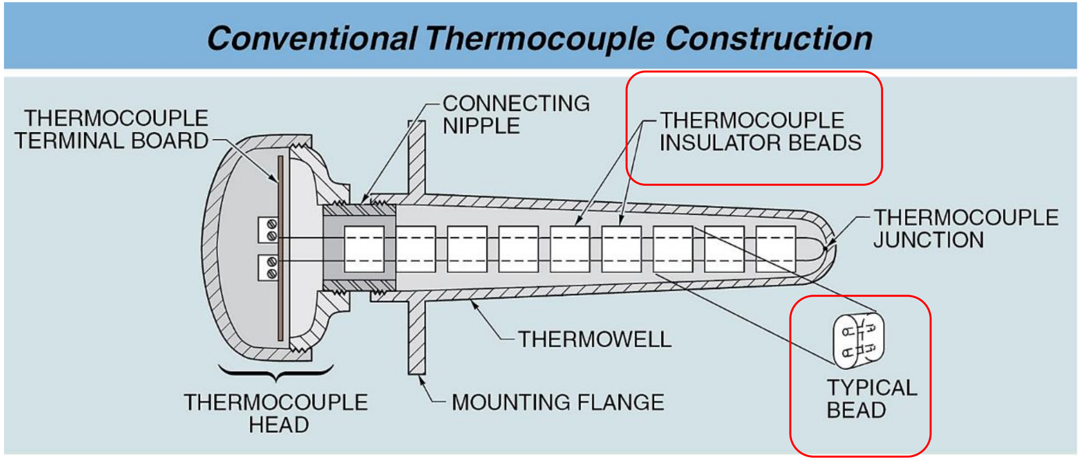
- voltage to temperature conversion
- cold junction compensation
- and a digital readout of the temperature.

Thermocouple Applications

Fluke Corporation

Use of thermowell will help to avoid the corrosion
Thermowell increase the sensor response time over all.

Conventional thermocouple construction uses insulator beads to isolate the two thermocouple wires.



Thermocouple Types:

Thermocouple tables

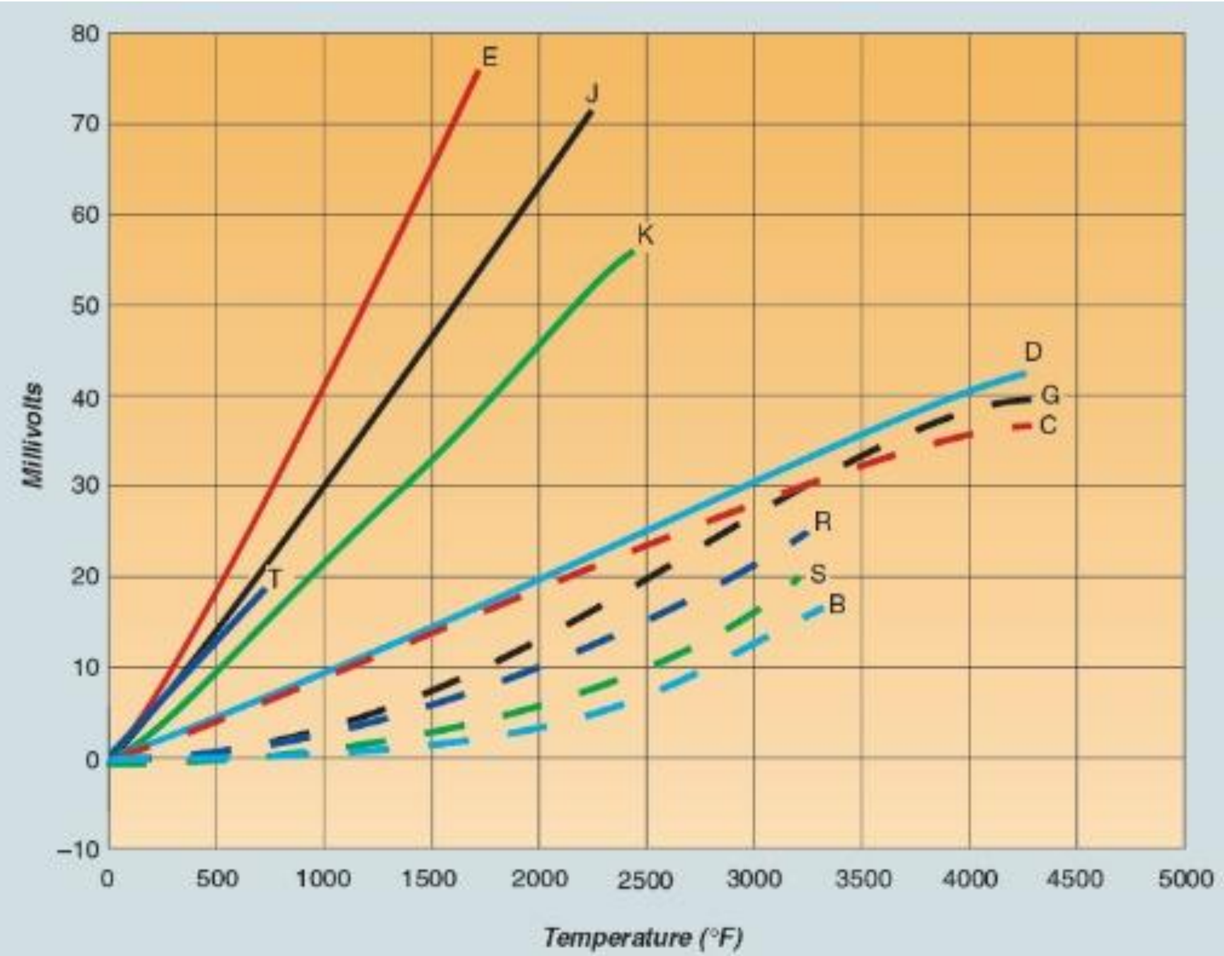
Type E: chromel—constantan
Type J: iron—constantan
Type K: chromel—alumel
Type N: nicrosil—nisil
Type S: platinum/10% rhodium−platinum
Type T: copper−constantan

Designation	Useful Temperature Range		Designation
	°F	°C	
B	122 to 3100	50 to 1700	Resistant to oxidation and corrosion; hydrogen, carbon, and some metals can contaminate the Pt/Rh wires; do not insert into metal tubes
R	32 to 2650	1 to 1450	Resistant to oxidation and corrosion; hydrogen, carbon, and some metals can contaminate the Pt/Rh wires; do not insert into metal tubes
S	32 to 2650	1 to 1450	Resistant to oxidation and corrosion; hydrogen, carbon, and some metals can contaminate the Pt/Rh wires; do not insert into metal tubes
E	–325 to 1650	–200 to 900	Highest emf output, acceptable in mildly oxidizing or reducing atmospheres
J	32 to 1340	1 to 750	Acceptable in vacuum or reducing atmospheres; not recommended for low temperatures
T	–325 to 700	–200 to 350	Acceptable in mildly oxidizing and reducing atmospheres, inert atmospheres, and vacuum and where moisture is present; low temperature and cryogenic applications
K	–325 to 2300	–200 to 1250	Acceptable in clean oxidizing and inert atmospheres; limited use in vacuum and reducing atmospheres
N	–450 to 2400	–270 to 1300	Alternative for Type K, more stable
C	32 to 4200	0 to 2315	Acceptable in vacuum, inert, or reducing atmospheres; poor oxidation resistance, subject to embrittlement
D	32 to 4200	0 to 2315	Acceptable in vacuum, inert, or reducing atmospheres; poor oxidation resistance, subject to embrittlement
G	32 to 4200	0 to 2315	Acceptable in vacuum, inert, or reducing atmospheres; poor oxidation resistance, subject to embrittlement

Higher slope → more sensitive

TC selection factors:

- **Sensitivity**
- **Temperature range**
- **Resistance to extreme environments.**

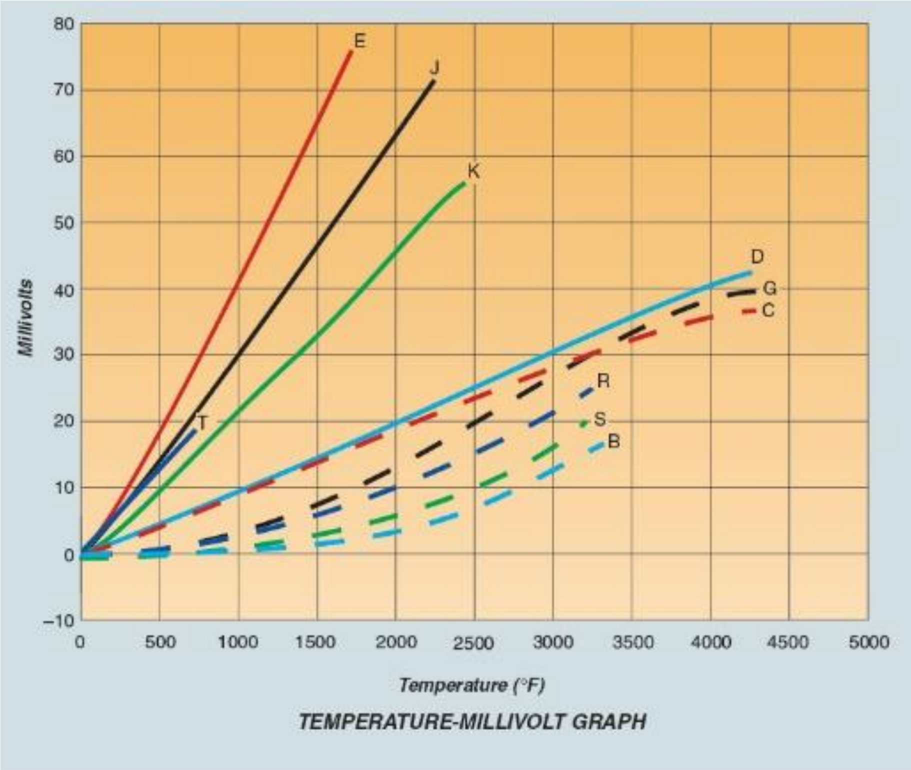


TEMPERATURE-MILLIVOLT GRAPH

Thermocouple Calculation

For some types of TCs the graph can be considered as linear graph for a certain range of temperature range with good approximation. Then the line slope would be the thermocouple sensitivity for whole given range.

K-type NiCR/NiAL	**a=4 mV/100°C**	**0°C...1100°C**
J-type Fe/CuNi	**a=5,3 mV/100°K**	**0°C...800°C**
R-type PtRh/Pt	**a=0,65 mV/100°C**	**0°C...1400°C**
Poly-Si – metal	**a≈ 20 mV/100 K (Depends on doping)**	



$$V \simeq a \times \Delta T$$

$$\Delta T = T_{Hot\ junction} - T_{Cold\ junction}$$

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Example 1

It is assumed that type J thermocouple is linear and has sensitivity of 0.0529 mv/ ℃ .

This TC generate 0 mv at 0 ℃ .

If the measured voltage is 17.8 mV with the reference junction in 0 ℃, what is corresponding temperature?

$$V \simeq a \times \Delta T$$

$$\Delta T = T_{Hot\ junction} - T_{Cold\ junction}$$

$$b = 0.0529$$

$$17.8 = 0.0529 \times T \Rightarrow T = 336.5\,°\mathrm{C}$$

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Thermocouple Table

APPENDIX 3

Thermocouple tables

Type E: chromel—constantan

Type J: iron—constantan

Type K: chromel—alumel

Type N: nicrosil—nisil

Type S: platinum/10% rhodium−platinum

Type T: copper−constantan

Temperature (°C)	Type E	Type J	Type K	Type N	Type S	Type T
−270	−9.834		−6.458	−4.345		
−260	−9.795		−6.441	−4.336		
−250	−9.719		−6.404	−4.313		
−240	−9.604		−6.344	−4.277		−6.105
−230	−9.456		−6.262	−4.227		−6.003
−220	−9.274		−6.158	−4.162		−5.891
−210	−9.063	−8.096	−6.035	−4.083		−5.753
−200	−8.824	−7.890	−5.891	−3.990		−5.603
−190	−8.561	−7.659	−5.730	−3.884		−5.438
−180	−8.273	−7.402	−5.550	−3.766		−5.261
−170	−7.963	−7.122	−5.354	−3.634		−5.070
−160	−7.631	−6.821	−5.141	−3.491		−4.865
−150	−7.279	−6.499	−4.912	−3.336		−4.648
−140	−6.907	−6.159	−4.669	−3.170		−4.419
−130	−6.516	−5.801	−4.410	−2.994		−4.177
−120	−6.107	−5.426	−4.138	−2.807		−3.923
−110	−5.680	−5.036	−3.852	−2.612		−3.656
−100	−5.237	−4.632	−3.553	−2.407		−3.378
−90	−4.777	−4.215	−3.242	−2.193		−3.089
−80	−4.301	−3.785	−2.920	−1.972		−2.788
−70	−3.811	−3.344	−2.586	−1.744		−2.475
−60	−3.306	−2.892	−2.243	−1.509		−2.152
−50	−2.787	−2.431	−1.889	−1.268	−0.236	−1.819
−40	−2.254	−1.960	−1.527	−1.023	−0.194	−1.475
−30	−1.709	−1.481	−1.156	−0.772	−0.150	−1.121
−20	−1.151	−0.995	−0.777	−0.518	−0.103	−0.757
−10	−0.581	−0.501	−0.392	−0.260	−0.053	−0.383
0	0.000	0.000	0.000	0.000	0.000	0.000

Continued

—cont'd

Temperature (°C)	Type E	Type J	Type K	Type N	Type S	Type T
10	0.591	0.507	0.397	0.261	0.055	0.391
20	1.192	1.019	0.798	0.525	0.113	0.789
30	1.801	1.536	1.203	0.793	0.173	1.196
40	2.419	2.058	1.611	1.064	0.235	1.611
50	3.047	2.585	2.022	1.339	0.299	2.035
60	3.683	3.115	2.436	1.619	0.365	2.467
70	4.329	3.649	2.850	1.902	0.432	2.908
80	4.983	4.186	3.266	2.188	0.502	3.357
90	5.646	4.725	3.681	2.479	0.573	3.813
100	6.317	5.268	4.095	2.774	0.645	4.277
110	6.996	5.812	4.508	3.072	0.719	4.749
120	7.683	6.359	4.919	3.374	0.795	5.227
130	8.377	6.907	5.327	3.679	0.872	5.712
140	9.078	7.457	5.733	3.988	0.950	6.204
150	9.787	8.008	6.137	4.301	1.029	6.702
160	10.501	8.560	6.539	4.617	1.109	7.207
170	11.222	9.113	6.939	4.936	1.190	7.718
180	11.949	9.667	7.338	5.258	1.273	8.235
190	12.681	10.222	7.737	5.584	1.356	8.757
200	13.419	10.777	8.137	5.912	1.440	9.286
210	14.161	11.332	8.537	6.243	1.525	9.820
220	14.909	11.887	8.938	6.577	1.611	10.360
230	15.661	12.442	9.341	6.914	1.698	10.905
240	16.417	12.998	9.745	7.254	1.785	11.456
250	17.178	13.553	10.151	7.596	1.873	12.011
260	17.942	14.108	10.560	7.940	1.962	12.572
270	18.710	14.663	10.969	8.287	2.051	13.137
280	19.481	15.217	11.381	8.636	2.141	13.707
290	20.256	15.771	11.793	8.987	2.232	14.281
300	21.033	16.325	12.207	9.340	2.323	14.860
310	21.814	16.879	12.623	9.695	2.414	15.443
320	22.597	17.432	13.039	10.053	2.506	16.030
330	23.383	17.984	13.456	10.412	2.599	16.621
340	24.171	18.537	13.874	10.772	2.692	17.217
350	24.961	19.089	14.292	11.135	2.786	17.816
360	25.754	19.640	14.712	11.499	2.880	18.420
370	26.549	20.192	15.132	11.865	2.974	19.027
380	27.345	20.743	15.552	12.233	3.069	19.638
390	28.143	21.295	15.974	12.602	3.164	20.252
400	28.943	21.846	16.395	12.972	3.260	20.869
410	29.744	22.397	16.818	13.344	3.356	
420	30.546	22.949	17.241	13.717	3.452	
430	31.350	23.501	17.664	14.091	3.549	
440	32.155	24.054	18.088	14.467	3.645	
450	32.960	24.607	18.513	14.844	3.743	
460	33.767	25.161	18.938	15.222	3.840	

Table continue

Temperature (°C)	Type E	Type J	Type K	Type N	Type S	Type T
470	34.574	25.716	19.363	15.601	3.938	
480	35.382	26.272	19.788	15.981	4.036	
490	36.190	26.829	20.214	16.362	4.135	
500	36.999	27.388	20.640	16.744	4.234	
510	37.808	27.949	21.066	17.127	4.333	
520	38.617	28.511	21.493	17.511	4.432	
530	39.426	29.075	21.919	17.896	4.532	
540	40.236	29.642	22.346	18.282	4.632	
550	41.045	30.210	22.772	18.668	4.732	
560	41.853	30.782	23.198	19.055	4.832	
570	42.662	31.356	23.624	19.443	4.933	
580	43.470	31.933	24.050	19.831	5.034	
590	44.278	32.513	24.476	20.220	5.136	
600	45.085	33.096	24.902	20.609	5.237	
610	45.891	33.683	25.327	20.999	5.339	
620	46.697	34.273	25.751	21.390	5.442	
630	47.502	34.867	26.176	21.781	5.544	
640	48.306	35.464	26.599	22.172	5.648	
650	49.109	36.066	27.022	22.564	5.751	
660	49.911	36.671	27.445	22.956	5.855	
670	50.713	37.280	27.867	23.348	5.960	
680	51.513	37.893	28.288	23.740	6.064	
690	52.312	38.510	28.709	24.133	6.169	
700	53.110	39.130	29.128	24.526	6.274	
710	53.907	39.754	29.547	24.919	6.380	
720	54.703	40.382	29.965	25.312	6.486	
730	55.498	41.013	30.383	25.705	6.592	
740	56.291	41.647	30.799	26.098	6.699	
750	57.083	42.283	31.214	26.491	6.805	
760	57.873	42.922	31.629	26.885	6.913	
770	58.663	43.563	32.042	27.278	7.020	
780	59.451	44.207	32.455	27.671	7.128	
790	60.237	44.852	32.866	28.063	7.236	
800	61.022	45.498	33.277	28.456	7.345	
810	61.806	46.144	33.686	28.849	7.454	
820	62.588	46.790	34.095	29.241	7.563	
830	63.368	47.434	34.502	29.633	7.672	
840	64.147	48.076	34.908	30.025	7.782	
850	64.924	48.717	35.314	30.417	7.892	
860	65.700	49.354	35.718	30.808	8.003	
870	66.473	49.989	36.121	31.199	8.114	
880	67.245	50.621	36.524	31.590	8.225	
890	68.015	51.249	36.925	31.980	8.336	
900	68.783	51.875	37.325	32.370	8.448	
910	69.549	52.496	37.724	32.760	8.560	
920	70.313	53.115	38.122	33.149	8.673	

Continued

Temperature (°C)	Type E	Type J	Type K	Type N	Type S	Type T
930	71.075	53.729	38.519	33.538	8.786	
940	71.835	54.341	38.915	33.926	8.899	
950	72.593	54.949	39.310	34.315	9.012	
960	73.350	55.553	39.703	34.702	9.126	
970	74.104	56.154	40.096	35.089	9.240	
980	74.857	56.753	40.488	35.476	9.355	
990	75.608	57.349	40.879	35.862	9.470	
1000	76.357	57.942	41.269	36.248	9.585	
1010		58.533	41.657	36.633	9.700	
1020		59.121	42.045	37.018	9.816	
1030		59.708	42.432	37.402	9.932	
1040		60.293	42.817	37.786	10.048	
1050		60.877	43.202	38.169	10.165	
1060		61.458	43.585	38.552	10.282	
1070		62.040	43.968	38.934	10.400	
1080		62.619	44.349	39.315	10.517	
1090		63.199	44.729	39.696	10.635	
1100		63.777	45.108	40.076	10.754	
1110		64.355	45.486	40.456	10.872	
1120		64.933	45.863	40.835	10.991	
1130		65.510	46.238	41.213	11.110	
1140		66.087	46.612	41.590	11.229	
1150		66.664	46.985	41.966	11.348	
1160		67.240	47.356	42.342	11.467	
1170		67.815	47.726	42.717	11.587	
1180		68.389	48.095	43.091	11.707	
1190		68.963	48.462	43.464	11.827	
1200		69.536	48.828	43.836	11.947	
1210			49.192	44.207	12.067	
1220			49.555	44.577	12.188	
1230			49.916	44.947	12.308	
1240			50.276	45.315	12.429	
1250			50.633	45.682	12.550	
1260			50.990	46.048	12.671	
1270			51.344	46.413	12.792	
1280			51.697	46.777	12.913	
1290			52.049	47.140	13.034	
1300			52.398	47.502	13.155	
1310			52.747		13.276	
1320			53.093		13.397	
1330			53.438		13.519	
1340			53.782		13.640	
1350			54.125		13.761	
1360			54.467		13.883	
1370			54.807		14.004	
1380					14.125	

Example 2

If the voltage output measured from a Type-E thermocouple is 13.419 mV with the reference junction in 0 ℃, what is corresponding temperature?

Answer: 200 ℃

Temperature (°C)	Type E	T
10	0.591	0.
20	1.192	1.
30	1.801	1.
40	2.419	2.
50	3.047	2.
60	3.683	3.
70	4.329	3.
80	4.983	4.
90	5.646	4.
100	6.317	5.
110	6.996	5.
120	7.683	6.
130	8.377	6.
140	9.078	7.
150	9.787	8.
160	10.501	8.
170	11.222	9.
180	11.949	9.
190	12.681	1
200	13.419	1
210	14.161	1
220	14.909	1
230	15.661	1
240	16.417	1
250	17.178	1
260	17.942	1

Example 3

If the emf output measured from a Type-E thermocouple with cold junction in 0 °C is 10.72 mV, what is corresponding temperature?

—cont'd

Temperature (°C)	Type E
10	0.591
20	1.192
30	1.801
40	2.419
50	3.047
60	3.683
70	4.329
80	4.983
90	5.646
100	6.317
110	6.996
120	7.683
130	8.377
140	9.078
150	9.787
160	10.501
170	11.222
180	11.949
190	12.681

Point 1 = (160 °C , 10.501 mV)   Point 2=(170 °C , 11.222 mV)

$$mV = a \times T + b$$

$$a = \frac{11.222\ mV - 10.501\ mv}{170\ °C - 160\ °C} = 0.0721$$

$$10.501 mV = 0.0721 \times 160 + b \quad \Rightarrow b = -1.035\ mV$$

$$mV = 0.0721 \times T - 1.035$$

$$10.72 = 0.0721 \times T - 1.035 \Rightarrow \boxed{T = 163.04\ °C}$$

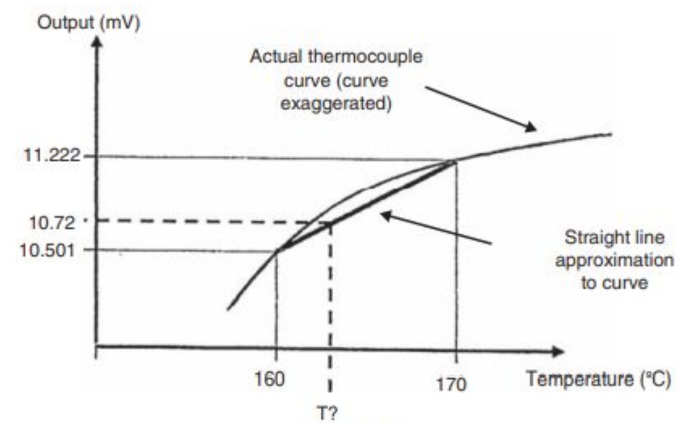
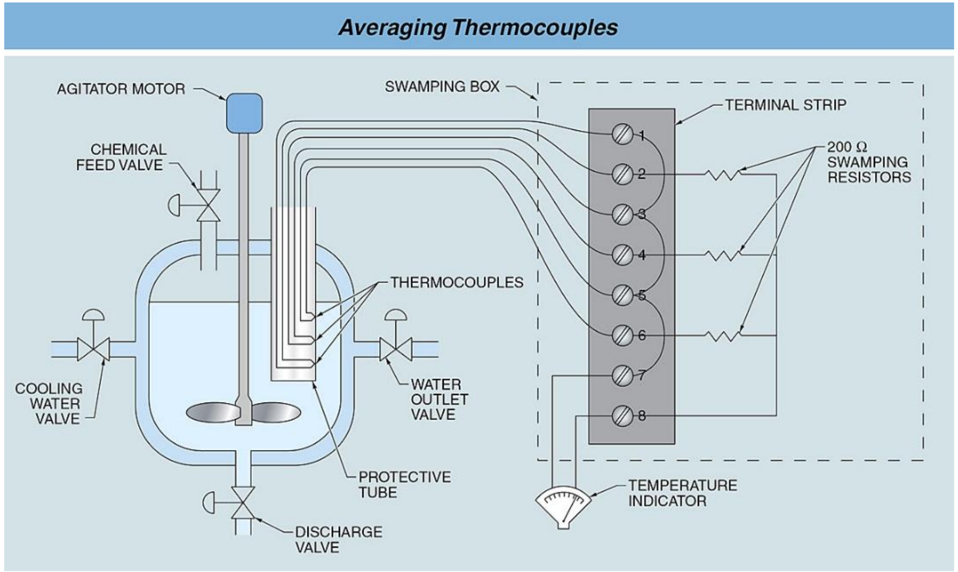


Figure 14.5
Procedure of interpolation between data points of a thermocouple table.

Averaging Thermocouple

An averaging thermocouple is an electrical thermometer consisting of a set of parallel-connected thermocouples that is commonly used to measure an average temperature of an object or area. For example, in a large tank or reactor, a set of thermocouples is inserted in a protective tube or thermowell in the top of the vessel.



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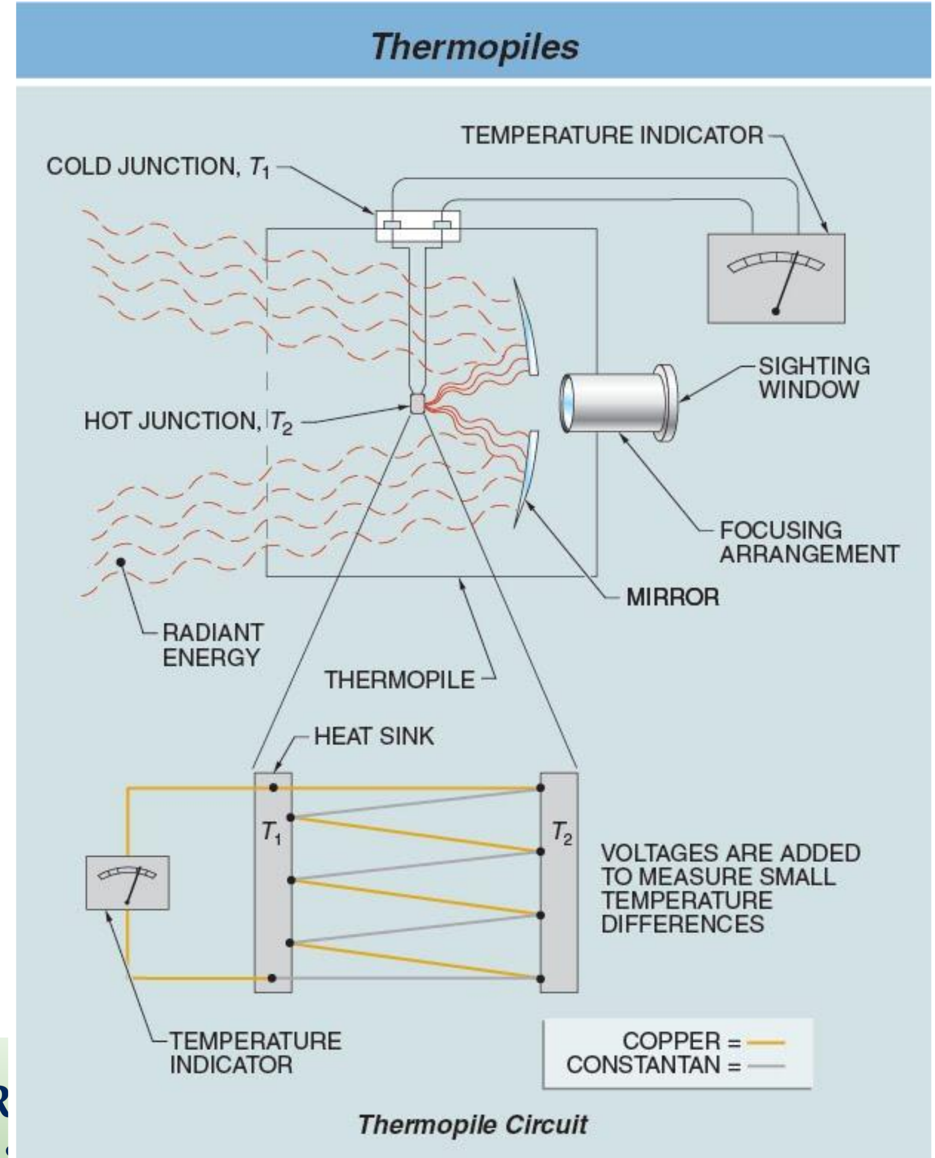
Thermopile

A thermopile is an electrical thermometer consisting of several thermocouples connected in series to provide a higher voltage output. In a thermopile, the individual voltages of each thermocouple are added together.

A thermopile can be used to measure extremely small temperature differences. Thermopiles have been designed that are capable of measuring temperature differences as small as a few millionths of a degree

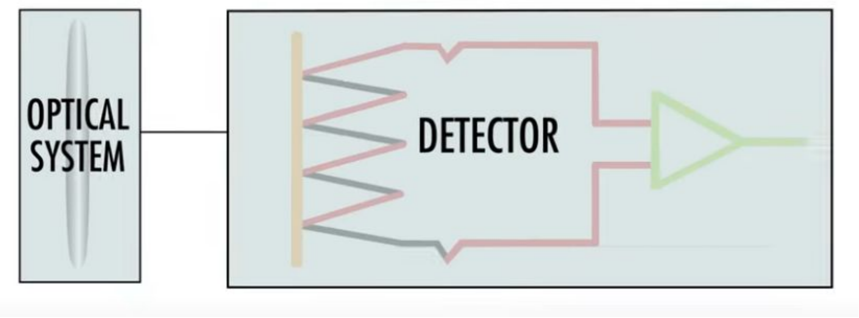


Thermopile Circuit

Pyrometer

Pyrometer measures the temperature remotely

Thermopile is used to convert the collected radiation to voltage.



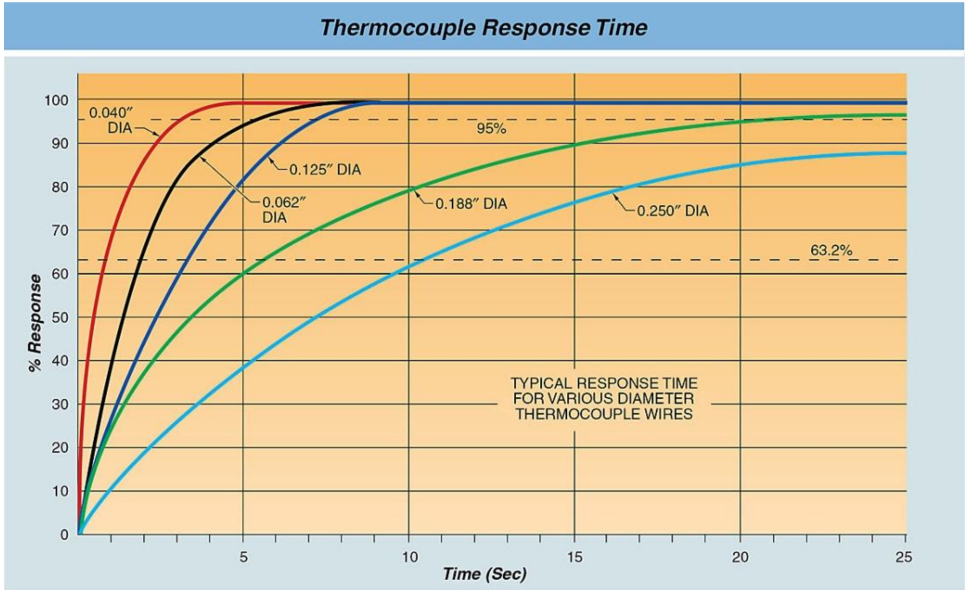
[What is a Pyrometer? (youtube.com)]

Thermocouple Response Time

One of the factors that affects the response time of a thermocouple is the thickness of the thermocouple wire or "thermocouple element".

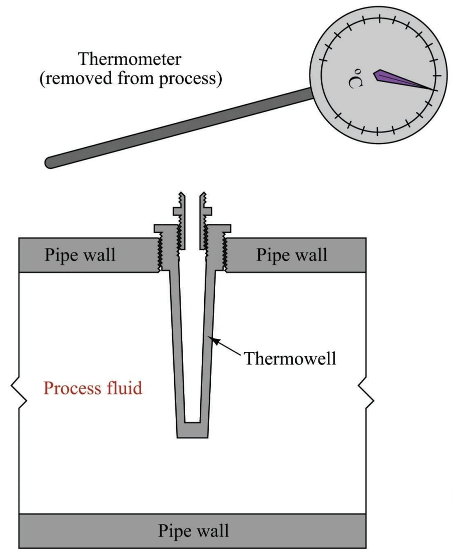
A thicker wire has more thermal mass, which means it takes longer to heat up or cool down in response to changes in temperature. This can result in slower response times, which can be a disadvantage in some applications.

A thin-film TC is faster but might have lower accuracy and higher cost to build.



Thermowell

- A thermowell is a closed tube used to protect a temperature instrument from process conditions and to allow instrument maintenance to be performed without draining the process fluid.
- Thermowells are also called thermocouple wells, sheaths, and protecting tubes.
- A thermowell provides the ability to remove the sensing element for servicing and calibration without having to shut down the process and drain a pipeline or reactor.
- Thermowell increase the response time.



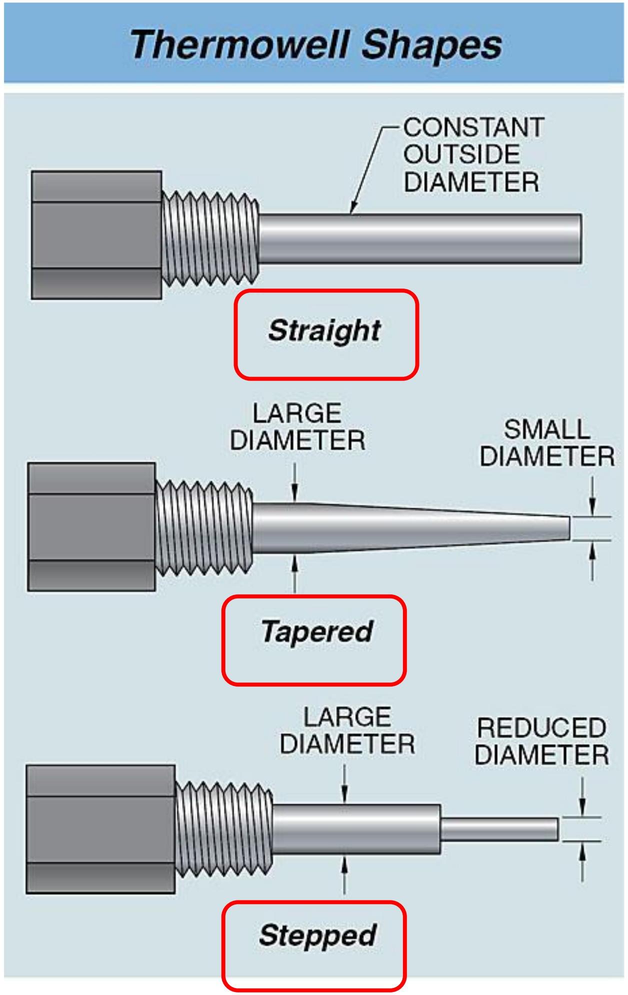
Thermowell

Thermocouple or RTD

Thermowell Shape

The most common thermowell is the stepped form, which has a larger insertion diameter over most of the length but steps down in diameter over the temperature-sensing end.

Tapered thermowells start with a large diameter at the process connection and have an even taper down to the tip. Tapered thermowells are used for high-pressure and high-stress, high speed applications because the wider base of the thermowell helps the thermowell resist the stresses of flowing fluids.



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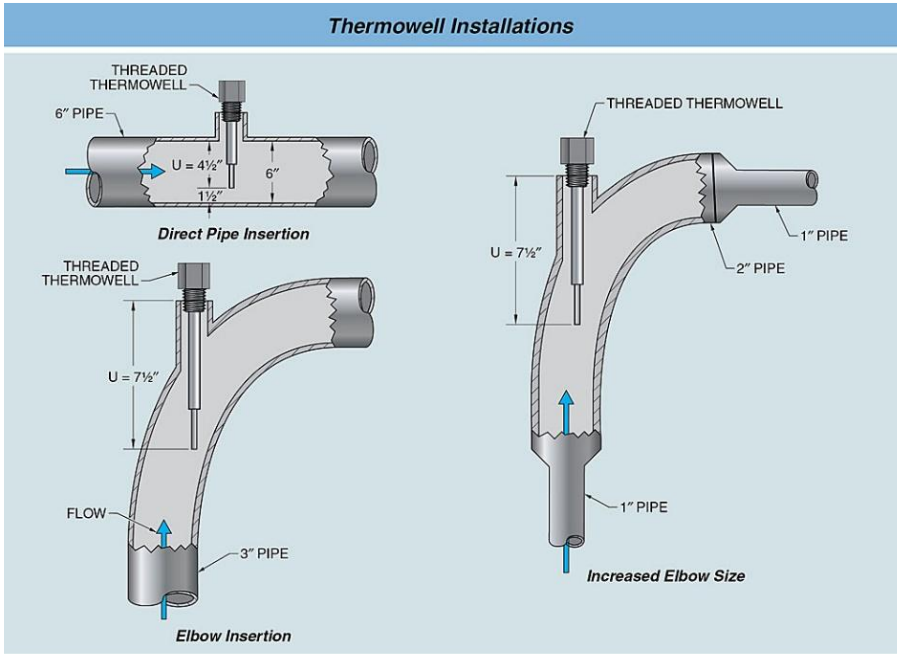
Thermowell Installation

- To ensure that the thermowell has the best chance of accurately sensing the process temperature, the sensitive portion of the insertion length must be in the actively flowing stream.
- It is difficult to insert a thermowell into the side of pipes smaller than 4″. It is far better to install thermowells into pipe elbows. This allows a longer insertion length to be used. The tip of the thermowell should face into the flowing stream.
- Thermowell installations in smaller pipes can cause a serious restriction of flow. In those cases, the piping is increased in size around the thermowell to ensure there is sufficient free space for the flow to get around the thermowell.



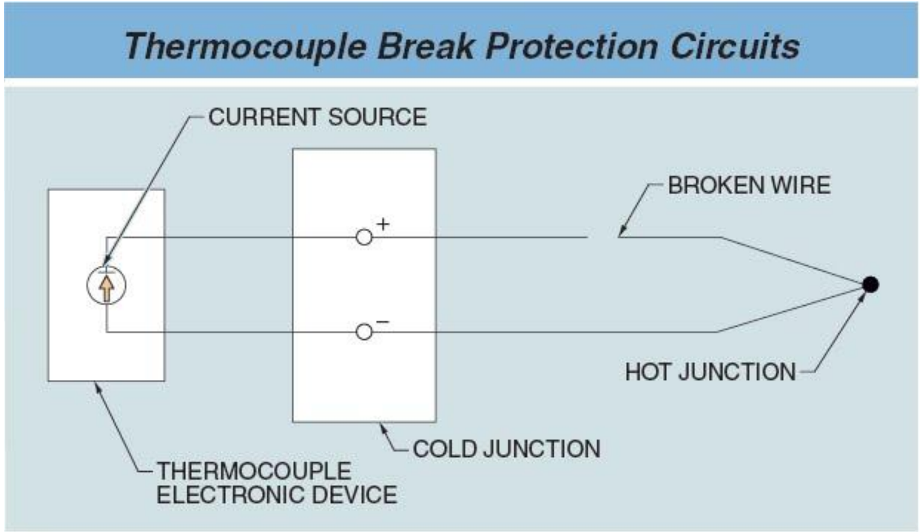
TC Break Protection

The thermocouple will show 0 volt when hot and cold junctions are at the same temperature $\Delta T=0$.

It will also show 0 volt whe the wire is broken.

This could be dangerous in some application, for example an oven should be turned off when temperature reaches to 200 ℃ . But because the wire is broken it never happens and the oven will overheat.

To detect a broken TC, an electrical current source is used. If the current does not circulates, the the TC wire is broken.

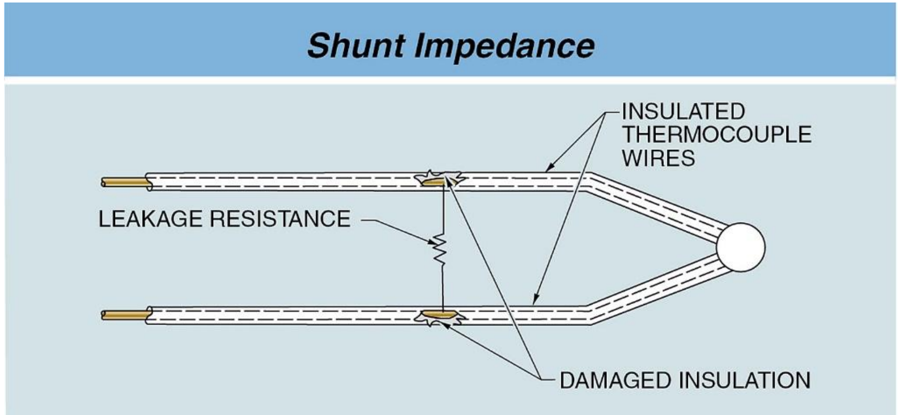


TC Leakage Resistance

It is necessary that two wires of TC be connected to each other at hot junction and be isolated from each other along the way to measurement point. Any other connection except the hot junction will replace the hot junction and the measured voltage will no represent temperature at hot junction.

The insulator of TC wires should appropriate to the temperature and condition of exposure environment.

If for any reason the insulators are damaged the electric current can pass from one wire to another. If the resistance of the contact point is less than resistance of thermocouple wire, then there is a leakage and thermocouple is damaged.



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Infrared Radiation Thermometers

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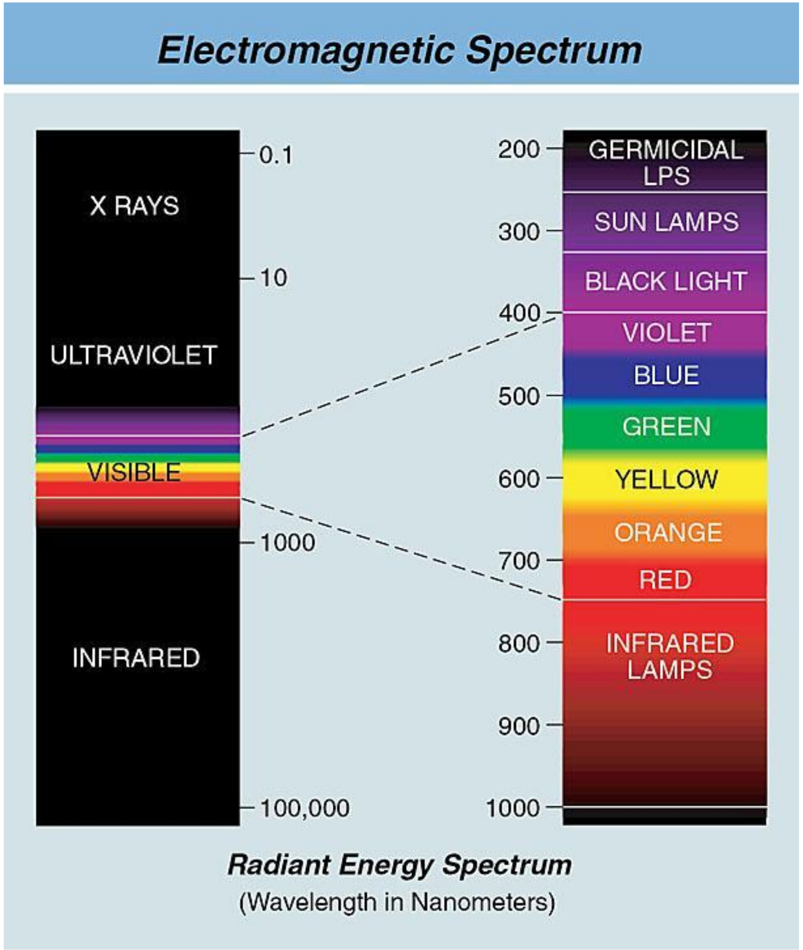
Infrared Radiation Thermometers

Bodies that are at thermal equilibrium must balance the energy entering that object, such as heat or light, with the energy leaving that object.

The energy leaving the surface of an object is often emitted as electromagnetic radiation.

An IR thermometer is a thermometer that measures the infrared radiation (IR) emitted by an object to determine its temperature.

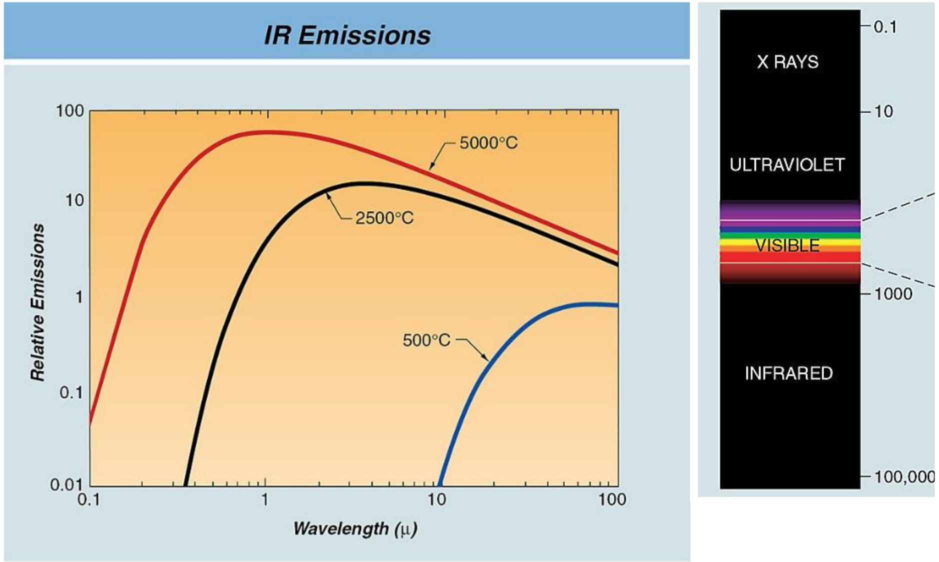
Infrared radiation is that part of the electromagnetic spectrum with longer wavelengths than visible light.



Relation between Wavelength & Temperature

The wavelength of infrared is inversely proportional to temperature. Ex, Higher temperature makes lower wavelength, then by measuring the wavelength, the temperature can be determined.

If a body is too hot wavelength will become smaller and it will enter to visible light. For example, as a steel billet is heated, its color changes from red at about 1112°F (600°C), to orange at about 1292°F (700°C), to yellow at about 2012°F (1100°C), and to white at about 2732°F (1500°C). The infrared segment of the electromagnetic spectrum is not visible, but the wavelength of the radiation can be measured.



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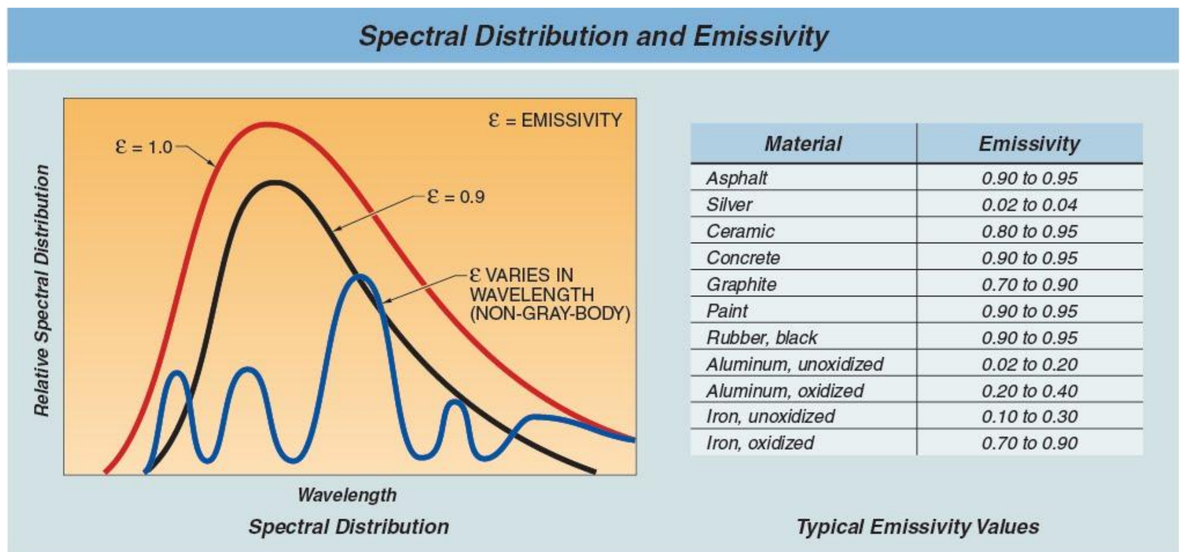
Emissivity

Emissivity is the ability of a body to emit radiation and is the ratio of the relative emissive power of any radiating surface to the emissive power of a blackbody radiator at the same temperature.

$$Emissivity = \frac{Total\ radiation\ from\ a\ non\text{-}black\text{-}body}{Total\ radiation\ from\ a\ blackbody}$$

For example, polished silver has an emissivity of 0.02 while dark asphalt has an emissivity of 0.95. In other words the dark material which absorb more heat compare to shiny materials , emit more to keep thermal equilibrium.



Material	Emissivity
Asphalt	0.90 to 0.95
Silver	0.02 to 0.04
Ceramic	0.80 to 0.95
Concrete	0.90 to 0.95
Graphite	0.70 to 0.90
Paint	0.90 to 0.95
Rubber, black	0.90 to 0.95
Aluminum, unoxidized	0.02 to 0.20
Aluminum, oxidized	0.20 to 0.40
Iron, unoxidized	0.10 to 0.30
Iron, oxidized	0.70 to 0.90

Typical Emissivity Values

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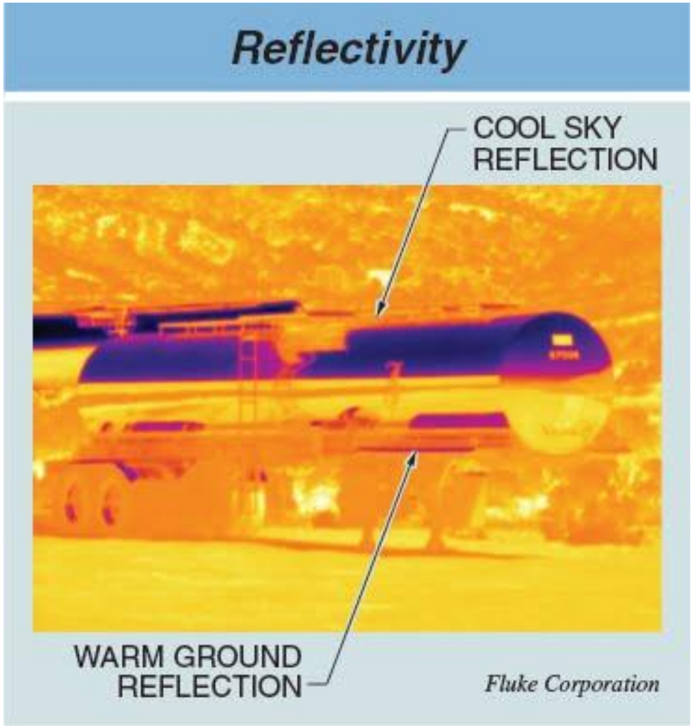
Emissivity vs Reflectivity

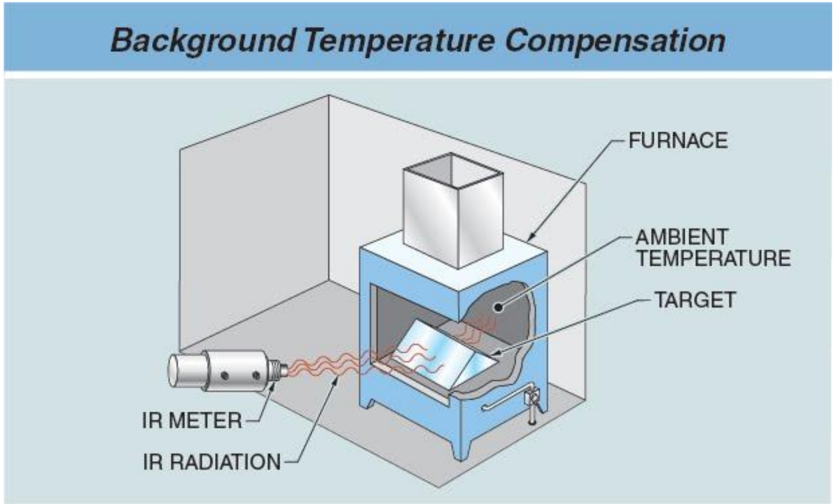
- Reflectivity is the ability of an object to reflect radiation.
- Bodies with a high emissivity reflect very little.
- Bodies with a low emissivity are very reflective.
- Materials with high reflectivity can be very hard to measure. For example, when heat radiates from the ground onto the bottom of a tanker truck, the shiny surface of the tank reflects the radiated heat and gives an inaccurate high temperature reading.
- The shiny surface can also reflect the cooler temperature of a clear sky onto the top of the tank, which gives an inaccurate low temperature reading.



Source of Inaccuracy

The background temperature can influence the temperature reading from an IR thermometer.

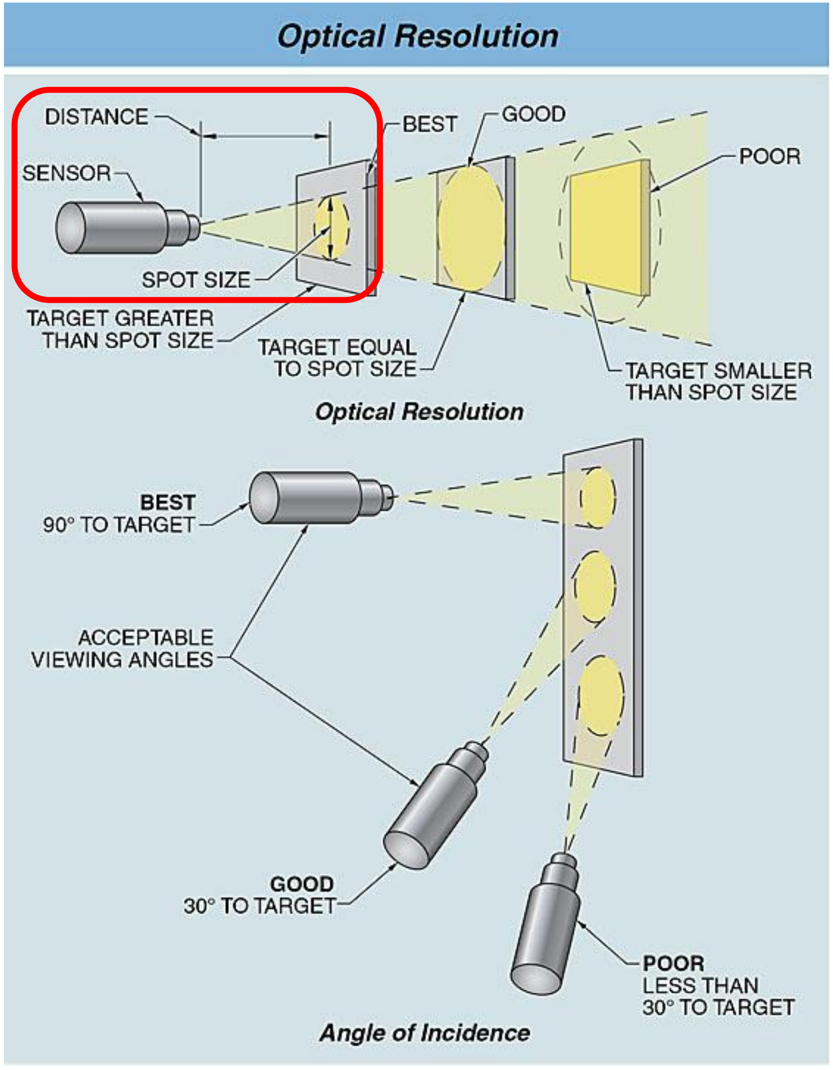
The emissivity correction performed by IR thermometers generally assumes that the hot body is in an ambient temperature environment. For example, if a painted automobile body exits a paint-drying oven at 200°F and has an emissivity of 0.95, then 5% of the infrared radiation detected by the IR thermometer is reflected from the ambient factory surroundings. If the 200°F automobile body is measured while inside the paint-drying oven and the inside walls of the paint-drying oven are 400°F, then the 5% is from a much hotter source. The assumption of ambient temperature reflection is no longer true and the temperature measurement by the IR thermometer is less accurate.



Source of Inaccuracy

The optical resolution and the angle of incidence determine whether a reliable and accurate temperature measurement can be made.

At distances other than the focus distance, the measured spot is different from that specified by the D:S ratio (Distance/Spot diameter). For best accuracy, the body to be measured must fill the field of view and the angle of incidence must be as close to 90° as is practical.
If the angle of incidence is not close to 90°, erroneous readings can occur because the spot size gets larger and the amount of incident radiation changes.



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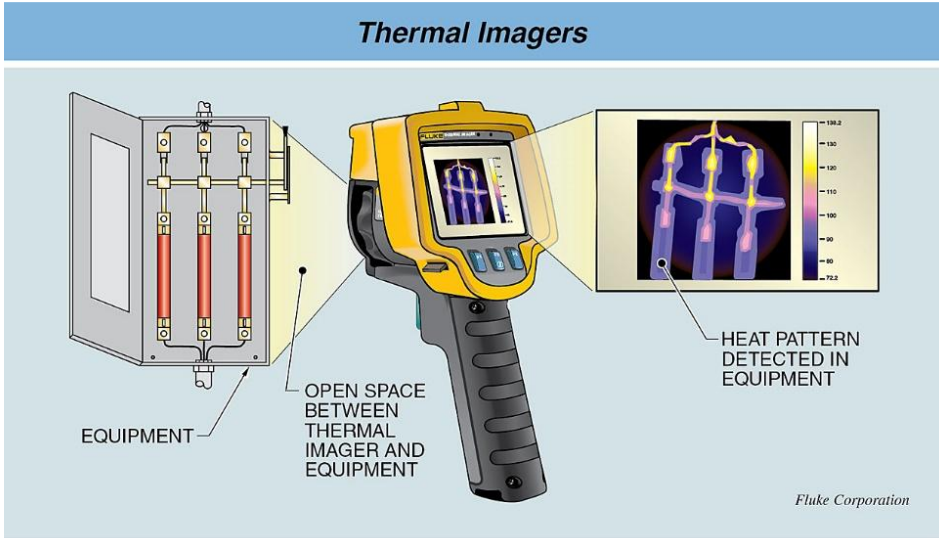
Thermal Imager

A thermal imager is an infrared device that uses a two-dimensional array of IR detectors to generate an image showing the temperature of an object.

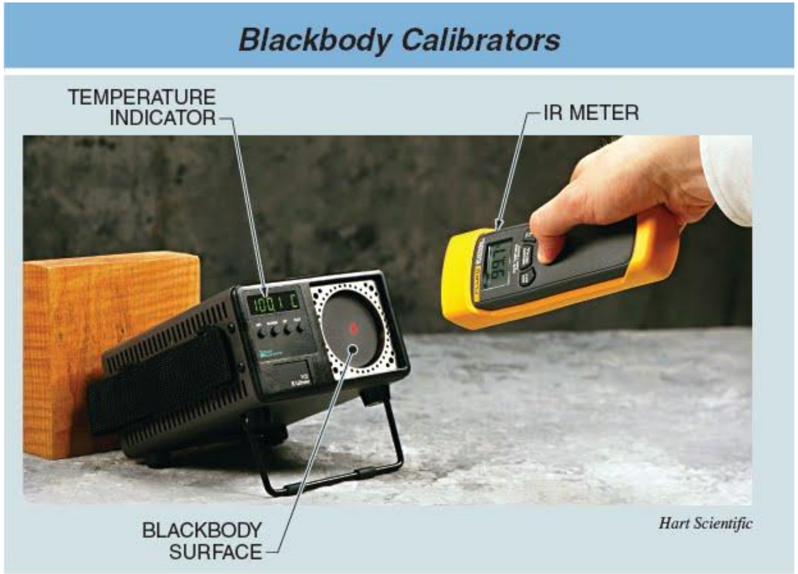
A non-radiometric thermal imager is an imager in which a surface-temperature image is generated but the actual temperature at a specific position is unknown.

A radiometric thermal imager is an imager in which the temperature measurement at all positions in the image is known.



IR Meter Calibration

A blackbody calibrator is a device used to calibrate infrared thermometers. Blackbody calibrators have unheated or heated surfaces whose emissivity is nearly 1.0. The temperature of the surface is often measured with a certified RTD. In operation, the surface is heated to a specified temperature and the IR thermometer is aimed at the spot on the calibrator. The manufacturer provides the actual emissivity value for the calibrator.



PIR Motion Detector Sensors

PIR stands for Passive Infrared Sensor.

They detect the infrared radiation emitted from human body or animal.

The word passive refers to the point that they do not send out any wave like ultrasound or laser to detect objects.

They are commonly used for security alarming and automatic light applications.

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