Ch.8: Temperature Measurement

- ***Temperature:***
  measure of hotness or coldness
  indicating the direction in which heat (energy) will spontaneously flow, i.e., from a hotter body (one at a higher temperature) to a colder one (one at a lower temperature).
- Temperature is not the equivalent of the system energy
- ***Historical background***

Temperature Measurement Devices

- ***thermocouples,***
- ***resistive temperature devices (RTDs and thermistors),***
- ***infrared radiators,***
- ***bimetallic devices,***
- ***liquid expansion devices, and***
- ***change-of-state devices.***

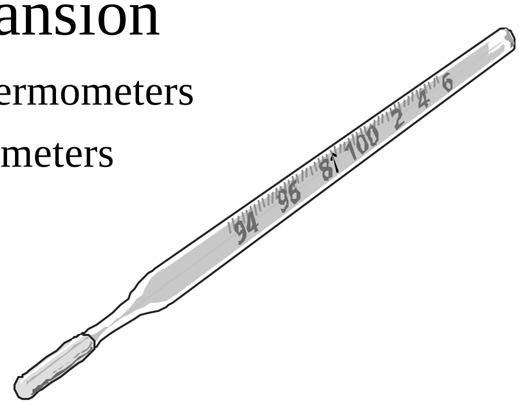
8.2: Temperature Standards

- ***Temperature scale*** (ITS-90)
- ***Definition of the degree***

  Kelvin K, defined as the 1/273.16 fraction of the thermodynamic temperature of the triple point of water (TPW).
- ***Fixed (reference) points***
- ***Interpolation between the fixed points***

8.3: Thermometry Based on Thermal Expansion

- Liquid-in-glass thermometers
- Bimetallic thermometers

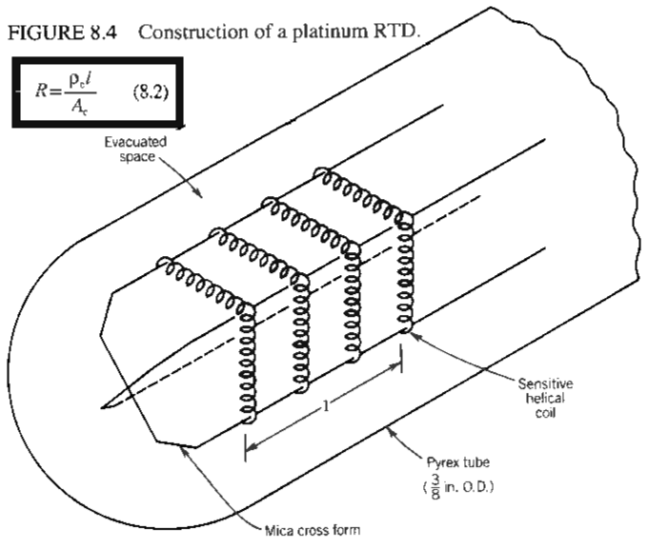


8.4: Electrical Resistance Thermometry

- RTD: Resistance Temperature Detectors
- RTD measurement circuits (Bridge circuits)
- Thermistors

FIGURE 8.4 Construction of a platinum RTD.

$$R = \frac{\rho_e l}{A_c} \quad (8.2)$$



8.5: Thermoelectric Temperature Measurements

- **Seebeck** effect: in dissimilar metals open circuit emf proportional to Δ T
- **Peltier** (refrigeration) effect: Δ T proportional to current I (reversible conversion of energy)
- **Thomson** (later Kelvin) effect: effect due to T gradients along a single conductor under current I

For I=0 only Seebeck effect!

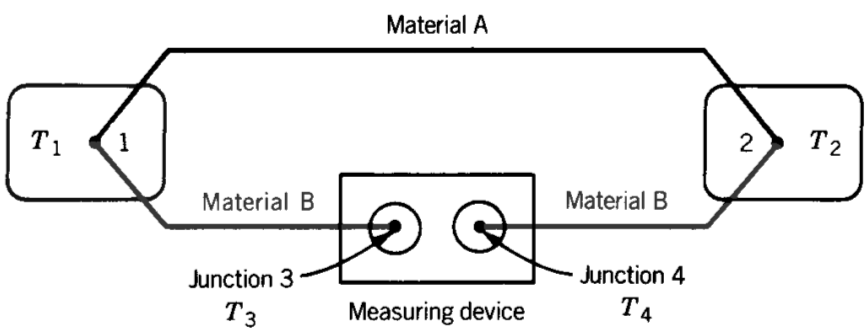
Fundamental Thermocouple Laws

- Law of homogeneous material (no emf at ΔT)
- Law of intermediate material (no emf at uniform T for dissimilar metals)
- Law of successive or intermediate temperature: $emf_{1-3}=emf_{1-2}+emf_{2-3}$

Measurement with Thermocouples

- TC measurement circuits with(out) reference junctions

FIGURE 8.14 Typical thermocouple measuring circuit.



Thermocouple Standards (“+” vs. “-”)

E: Chromel vs. Constantan

J: Iron vs. Constantan

K: Chromel vs. Alumel

S: Platinum/10% rhodium vs. Platinum

T: Copper vs. Constantan

ANSI Code	Alloy Combination		Color Coding		Maximum Temperature Range	EMF (mV) Over Max. Temperature Range	Limits of Error (Whichever is Greater)	
	+ Lead	– Lead	Thermocouple Grade	Extension Grade			Standard	Special
J	IRON Fe (magnetic)	CONSTANTAN COPPER-NICKEL Cu-Ni	+ ±	+ ±	–210 to 1200°C, –346 to 2193°F Thermocouple Grade 0 to 200°C, 32 to 392°F Extension Grade	–8.095 to 69.553	2.2°C or 0.75%	1.1°C or 0.4%
K	CHROMEGA NICKEL-CHROMIUM Ni-Cr	ALOMEGA NICKEL-ALUMINIUM Ni-Al (magnetic)	+ ±	+ ±	–270 to 1372°C, –454 to 2501°F Thermocouple Grade 0 to 200°C, 32 to 392°F Extension Grade	–6.458 to 54.886	2.2°C or 0.75% Above 0°C 2.2°C or 2.0% Below 0°C	1.1°C or 0.4%
V*	COPPER Cu	CONSTANTAN COPPER-NICKEL Cu-Ni	NONE ESTABLISHED	NONE ESTABLISHED	0 to 80°C 32 to 176°F Extension Grade			
T	COPPER Cu	CONSTANTAN COPPER-NICKEL Cu-Ni	+ ±	+ ±	–270 to 400°C –454 to 752°F Thermocouple Grade –60 to 100°C, –76 to 212°F Extension Grade	–6.258 to 20.872	1.0°C or 0.75% Above 0°C 1.0°C or 1.5% Below 0°C	0.5°C or 0.4%
E	CHROMEGA NICKEL-CHROMIUM Ni-Cr	CONSTANTAN COPPER-NICKEL Cu-Ni	+ ±	+ ±	–270 to 1000°C –454 to 1832°F Thermocouple Grade 0 to 200°C, 32 to 392°F Extension Grade	–9.835 to 76.373	1.7°C or 0.5% Above 0°C 1.7°C or 1.0% Below 0°C	1.0°C or 0.4%
N	OMEGA-P NICROSIL Ni-Cr-Si	OMEGA-N NISIL Ni-Si-Mg	+ ±	+ ±	–270 to 1300°C, –450 to 2372°F Thermocouple Grade 0 to 200°C, 32 to 392°F Extension Grade	–4.345 to 47.513	2.2°C or 0.75% Above 0°C 2.2°C or 2.0% Below 0°C	1.1°C or 0.4%
R	PLATINUM-13% RHODIUM Pt-13% Rh	PLATINUM Pt	NONE ESTABLISHED	+ ±	–50 to 1768°C –58 to 3214°F Thermocouple Grade 0 to 150°C, 32 to 300°F Extension Grade	–0.226 to 21.101	1.5°C or 0.25%	0.6°C or 0.1%
S	PLATINUM-10% RHODIUM Pt-10% Rh	PLATINUM Pt	NONE ESTABLISHED	+ ±	–50 to 1768°C –58 to 3214°F Thermocouple Grade 0 to 150°C, 32 to 300°F Extension Grade	–0.236 to 18.693	1.5°C or 0.25%	0.6°C or 0.1%

Thermocouple emf (Tables)

$$\text{Emf} = E = \Sigma c_i T^i$$

$i=0,1,2,\ldots 8$ (or 14)

see Text TABLE 8.7 on p.313

or:

Reference Functions for Thermocouple Types J and T: Table 8.7 (MathCAD)

Multiple-Junction TC Circuits

- Thermopiles (in series)
- Parallel arrangements

FIGURE 8.20 Thermopile arrangement.

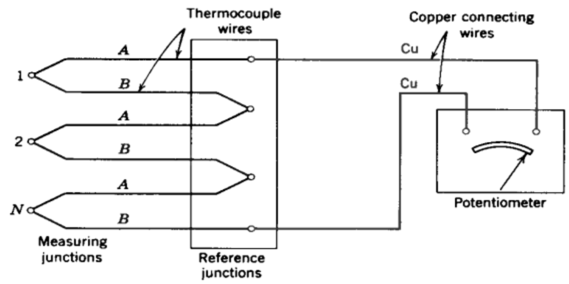
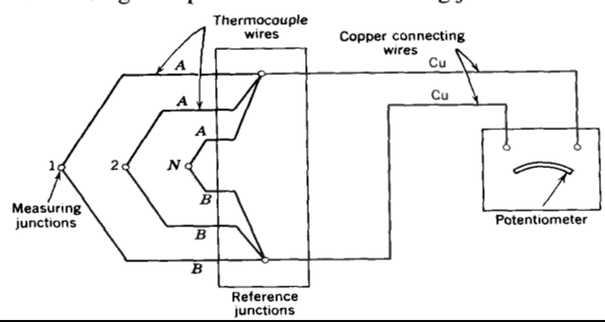


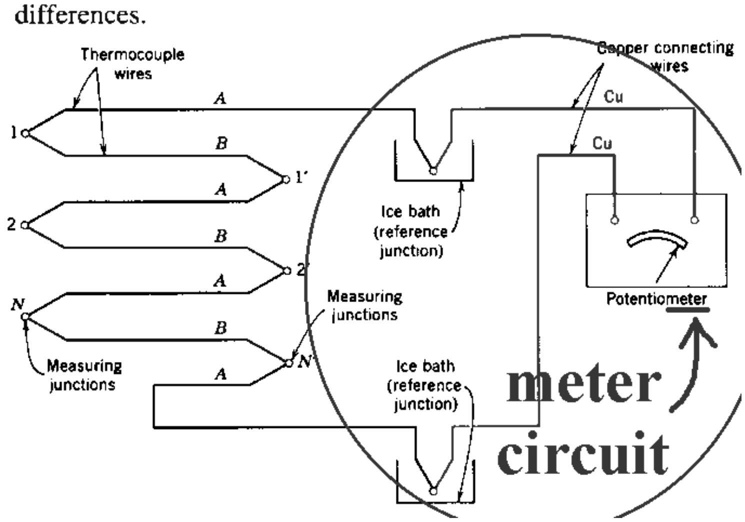
FIGURE 8.22
Parallel arrangement of thermocouples for sensing the average temperature of the measuring junctions.



Multiple-Junction TC Circuits

Thermopiles (in series)

FIGURE 8.21
Thermocouples arranged to sense temperature differences.



Problem 8.29:

For the given data (see the next slide), determine the **required number of thermopile junctions N** for the T-type thermocouple **to yield an uncertainty in heat loss Q of ±5%,** assuming the uncertainty in all other variables, but ΔT, may be neglected.

Problem 8.29:

Given

Table 8.7 (MathCAD)

$T-type\ T.C.$

$Q = kA_c \cdot \frac{\Delta T}{L}$

$A_c = 15 \cdot m^2$

$k = 0.4 \cdot \frac{W}{m^o C}$

$L = 0.25 \cdot m$

$\Delta T = 5 \cdot {}^o C$

$u_{emf} = 0.04 \cdot mV$

$\frac{u_{QR}}{Q} = 5\%$

$emf = f(T) = \sum c_i \cdot T^i$ @ $T = 40^o C$ avg. level

$u_{emf} = \frac{\partial(emf)}{\partial T} \cdot u_{\Delta T} = (\sum c_i \cdot i \cdot T^{i-1}) u_{\Delta T}$

$u_{\Delta t} = \frac{1}{(0.042 \cdot \frac{mV}{^o C})} \cdot (0.04 \cdot mV) = 0.95 \cdot {}^o C$

Find u_D

$Q_R = Q_N$

$u_Q = \frac{\partial Q}{\partial(\Delta T)} \cdot u_{\Delta T}; \quad \frac{u_{Q_N}}{Q} = \frac{u_{\Delta T}}{N \Delta T}$

Find N

$N = \frac{u_Q / Q}{u_{QR} / Q} = \frac{u_{\Delta T} / \Delta T}{u_{QR} / Q} = \frac{0.95/5}{5\%} = 3.8$

N=4