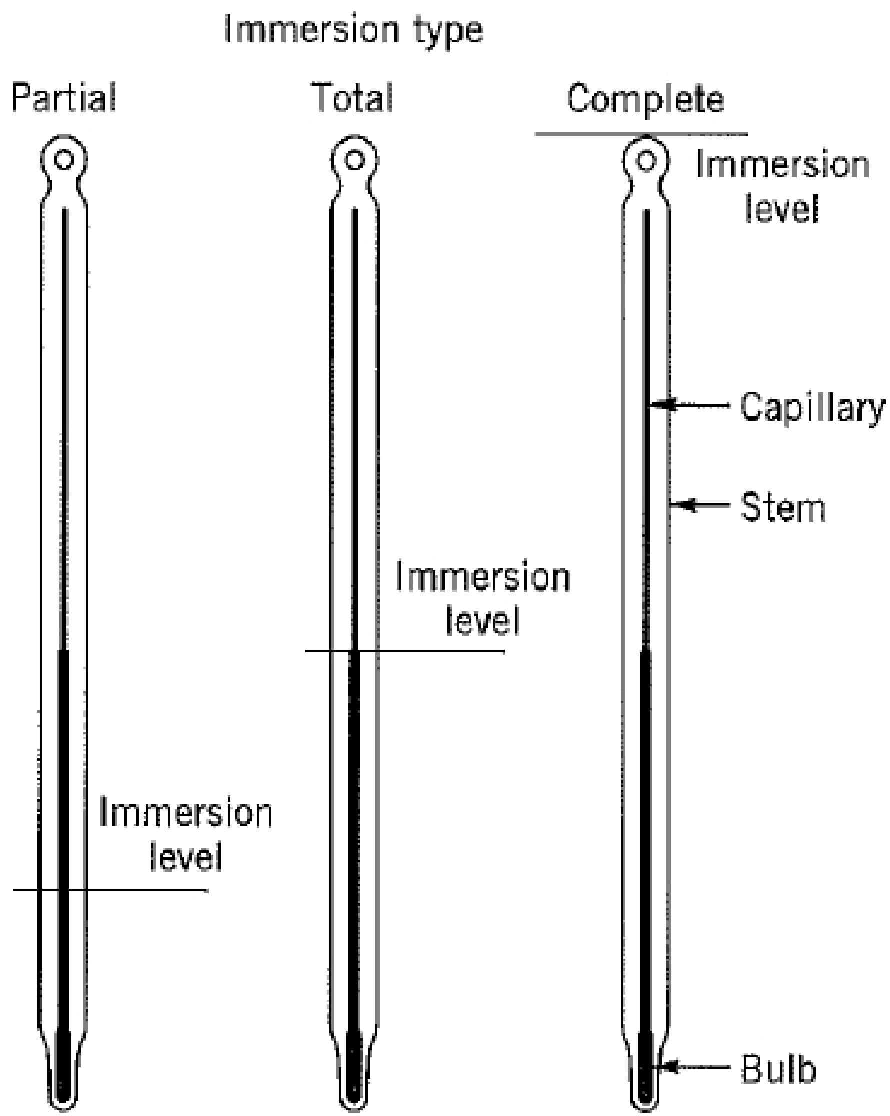
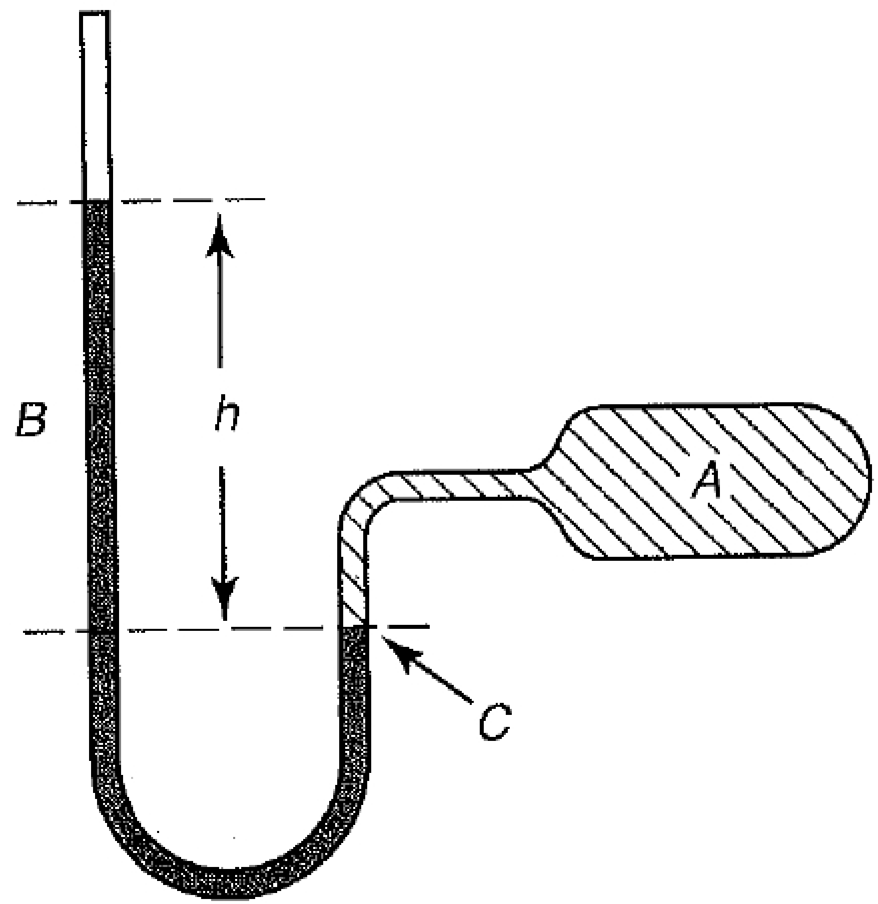
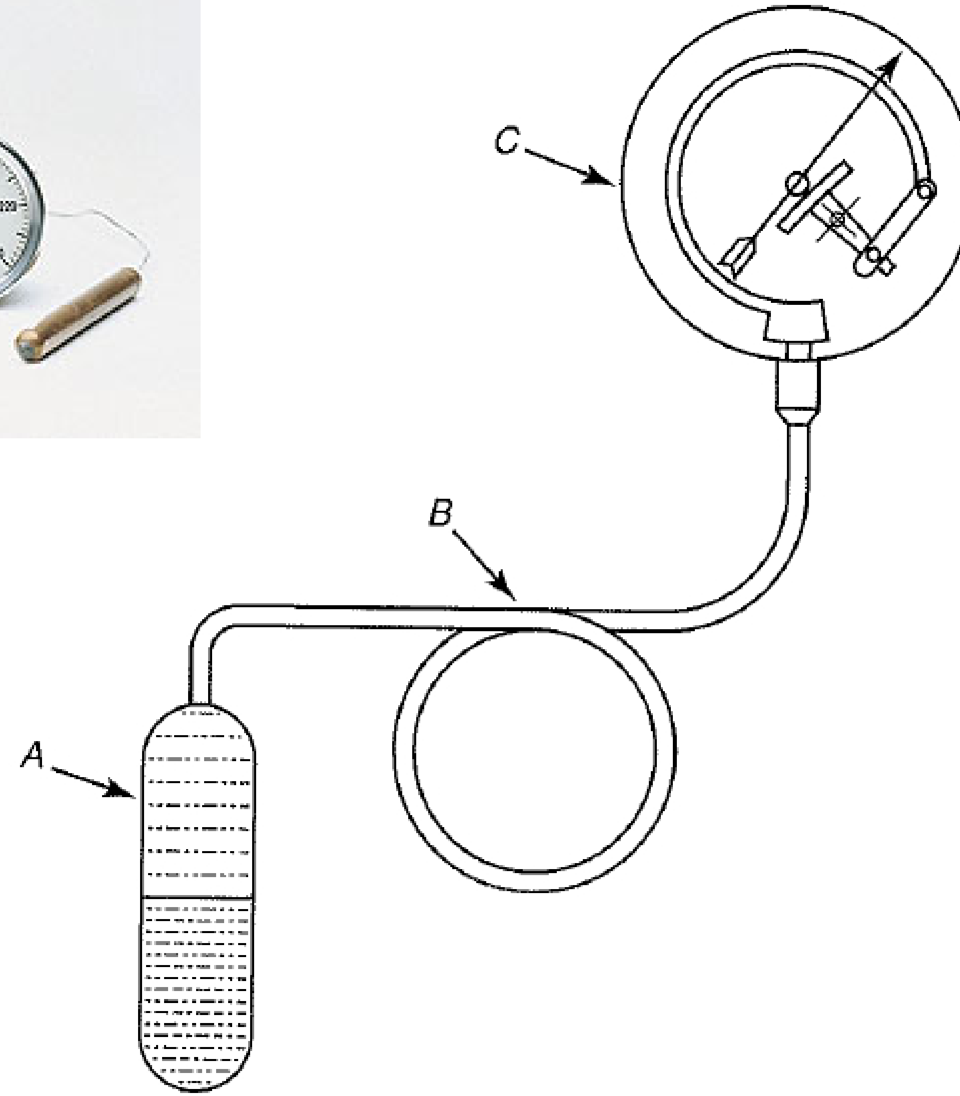
Temperature Measurement



Glass thermometers - 3 calibrations



Constant volume thermometer



Pressure thermometer

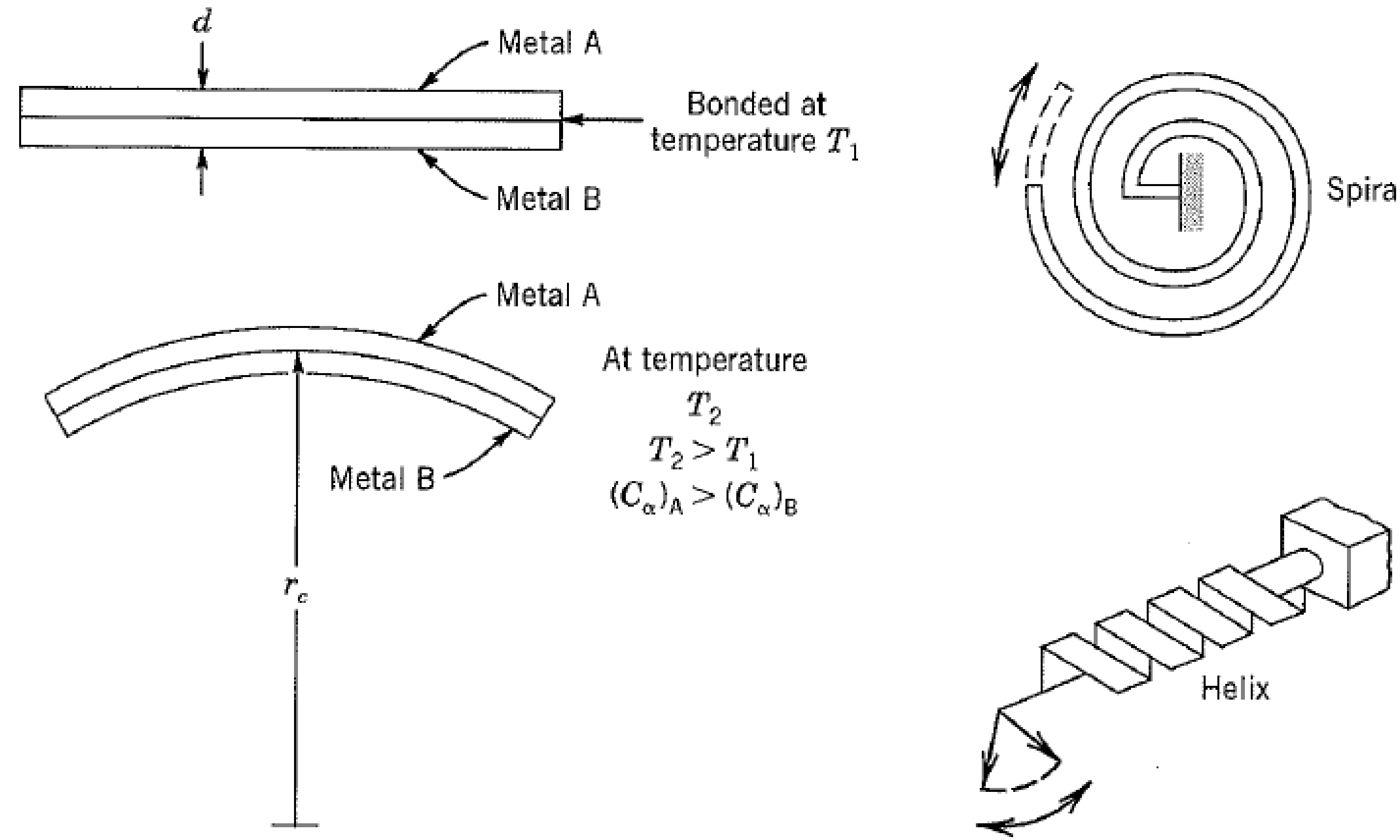
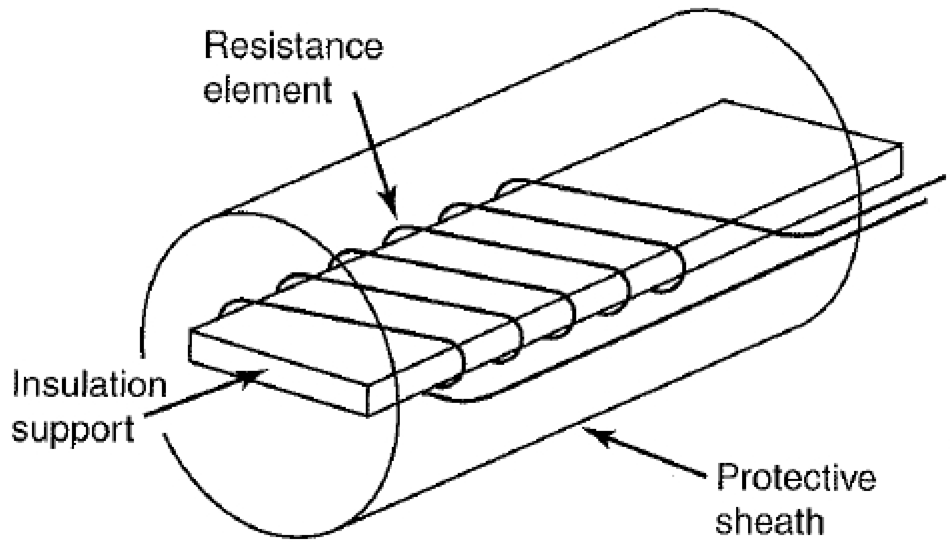


Figure 8.3 Expansion thermometry: bimetallic strip.

Invar C = 1.7 x 10^-8 m/m degree C
Iron   C = 1.2 x 10^-5 m/m degree C

60
40
80
20
100
0
120
-20
140
-40
160
°F
OMEGA
OMEGA ENGINEERING, INC
Stamford, Conn 06907

Resistive Temperature Detector - RTD



$$R = R_0[1 + \alpha(T - T_0) + \beta(T - T_0)^2 + \cdots]$$

$$R = R_0[1 + \alpha(T - T_0)]$$

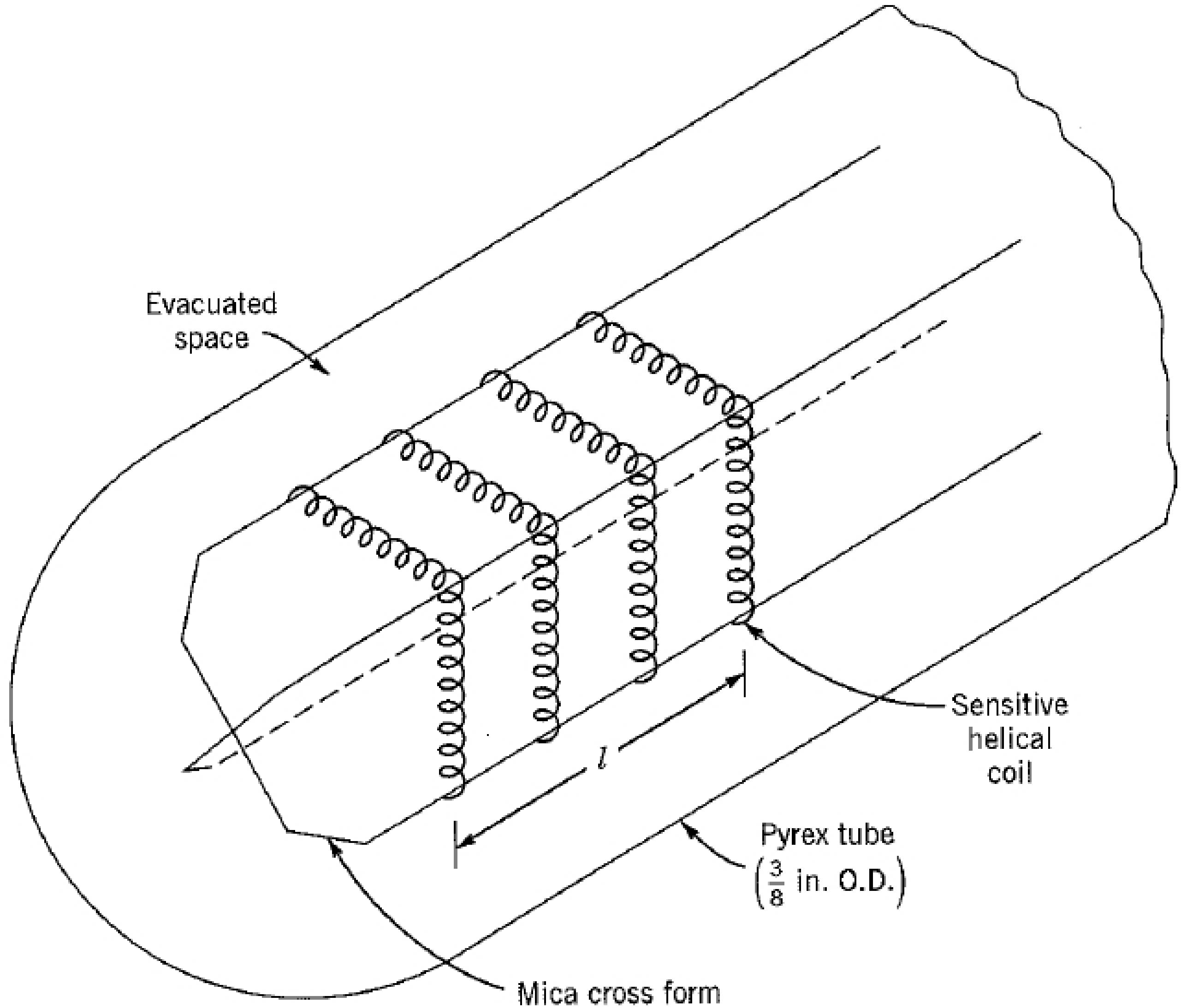
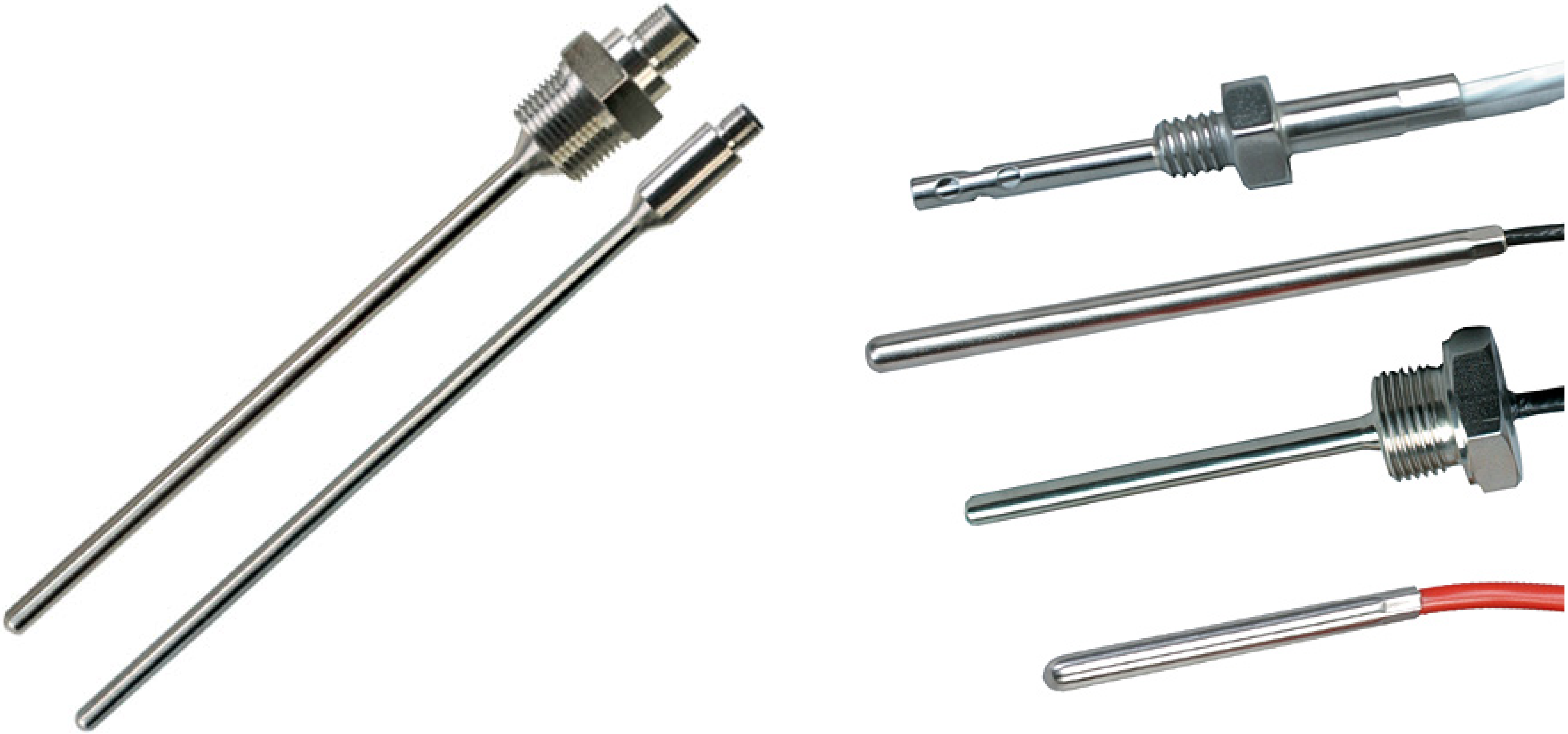
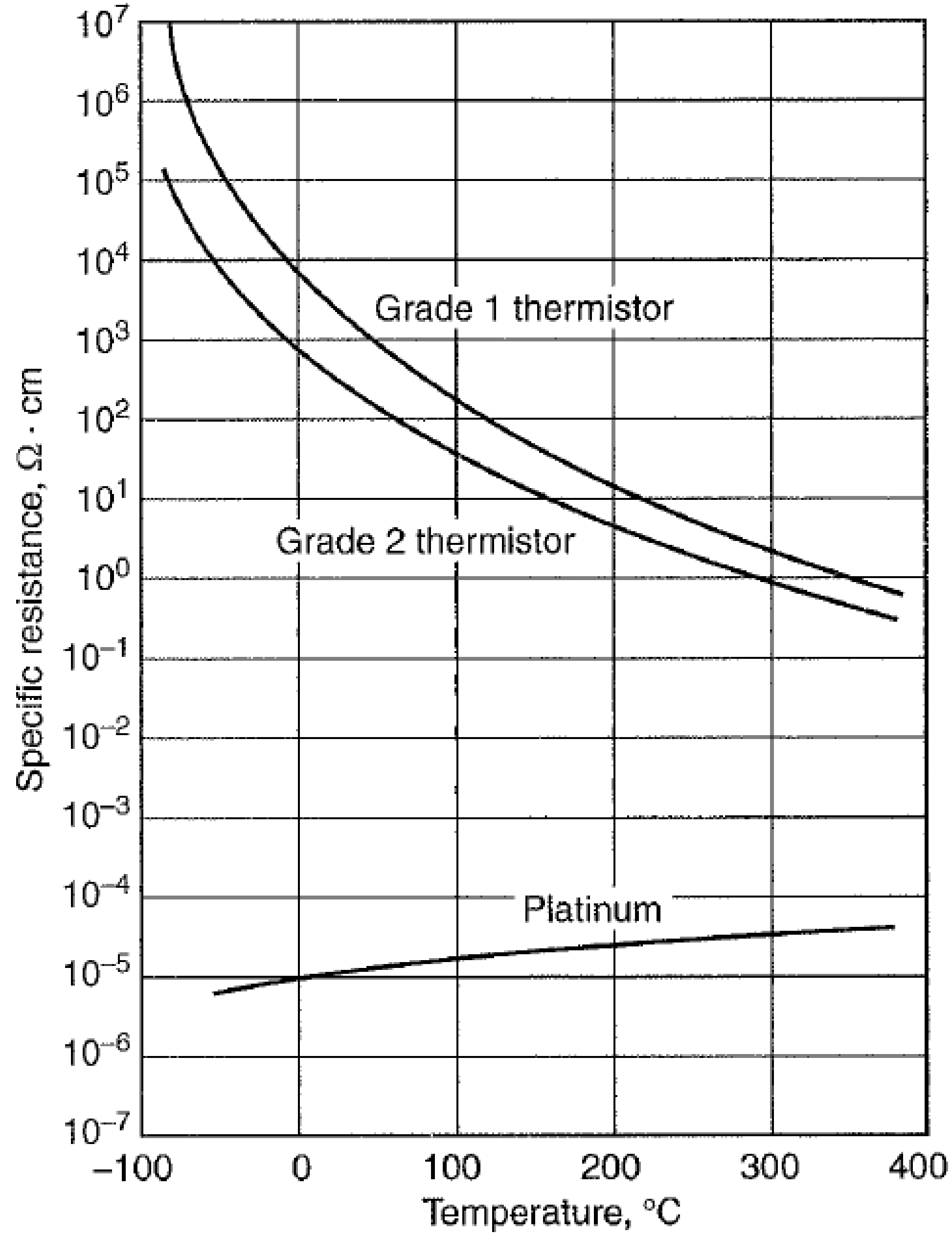


Figure 8.4 Construction of a platinum RTD. (From R. P. Benedict, *Fundamentals of Temperature, Pressure and Flow Measurements*, 3d ed., Wiley, New York, 1984.)

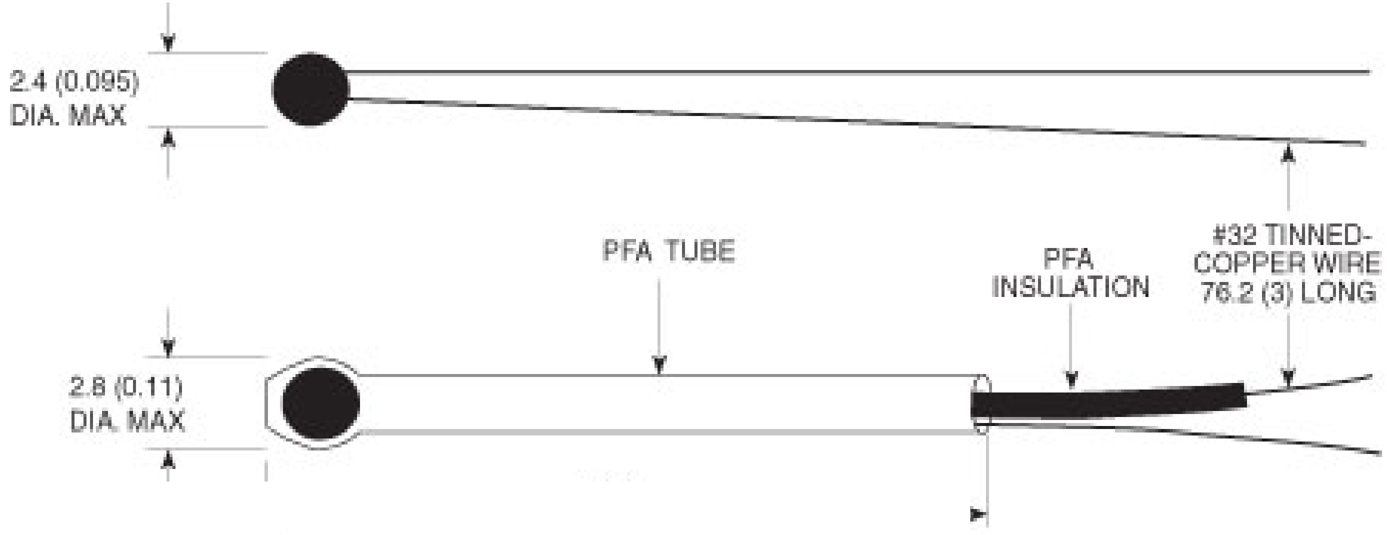


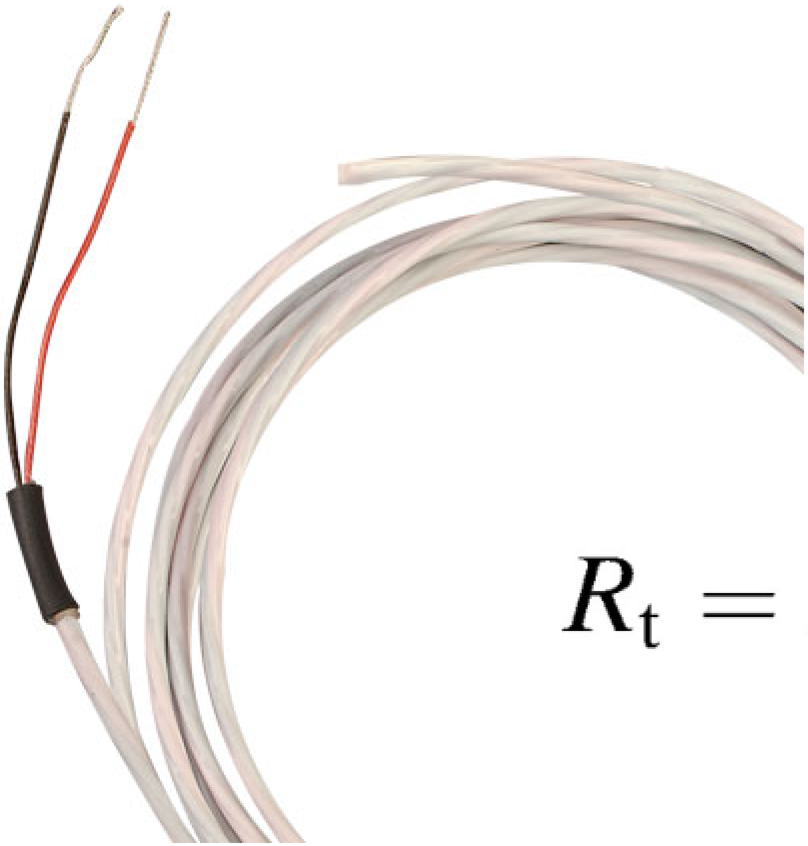
RTD sensors



10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^−1
10^−2
10^−3
10^−4
10^−5
10^−6
10^−7
Specific resistance, Ω · cm
Grade 1 thermistor
Grade 2 thermistor
Platinum
−100
0
100
200
300
400
Temperature, °C

Thermistor





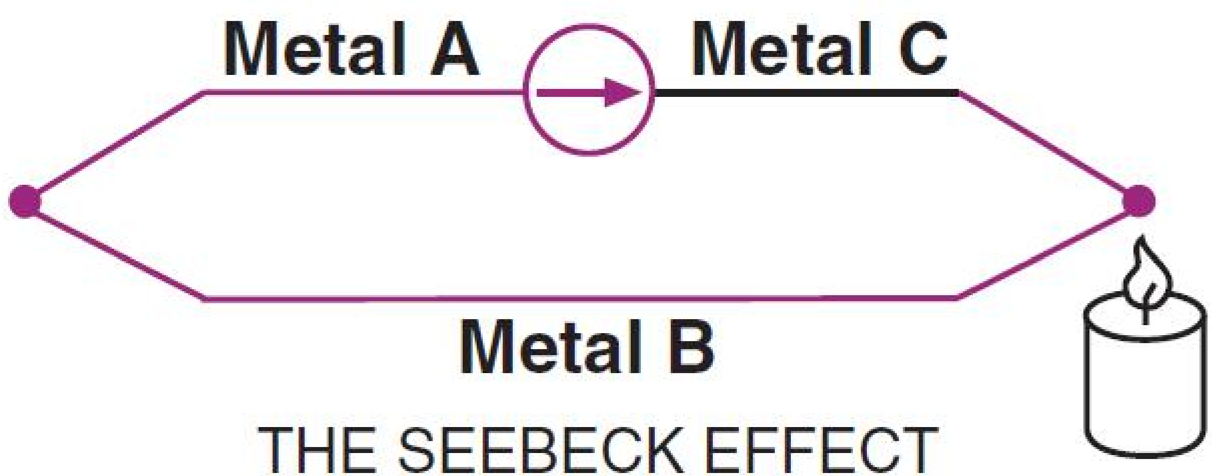
$$R_t = R_0 e^{[\beta(T_0 - T)/TT_0]}$$

Sheathed thermistor probe

Thermistors

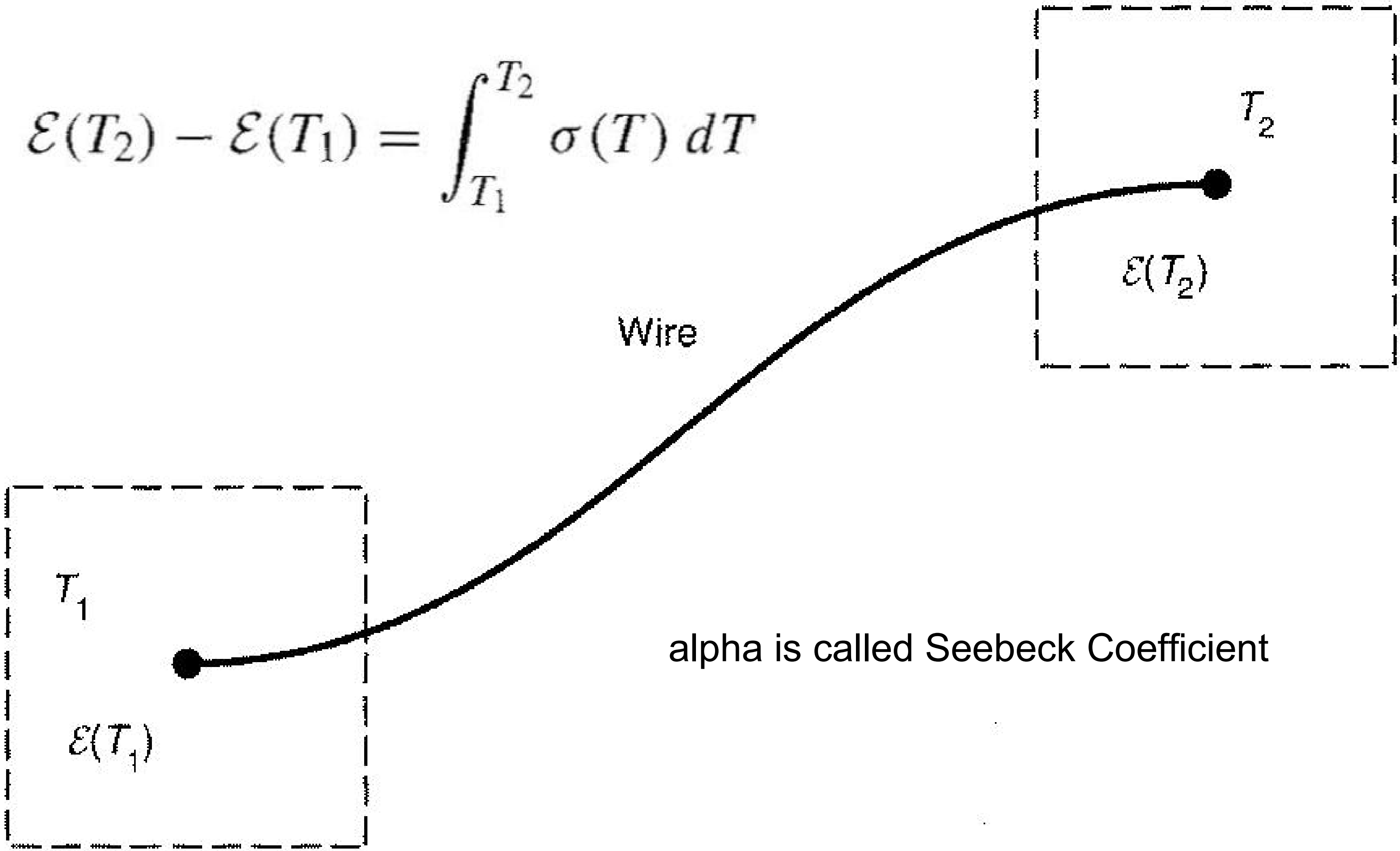
Thermocouple operation

When two wires composed of dissimilar metals are joined at both ends and one of the ends is heated, there is a continuous current which flows in the *thermoelectric* circuit. Thomas Seebeck made this discovery in 1821.

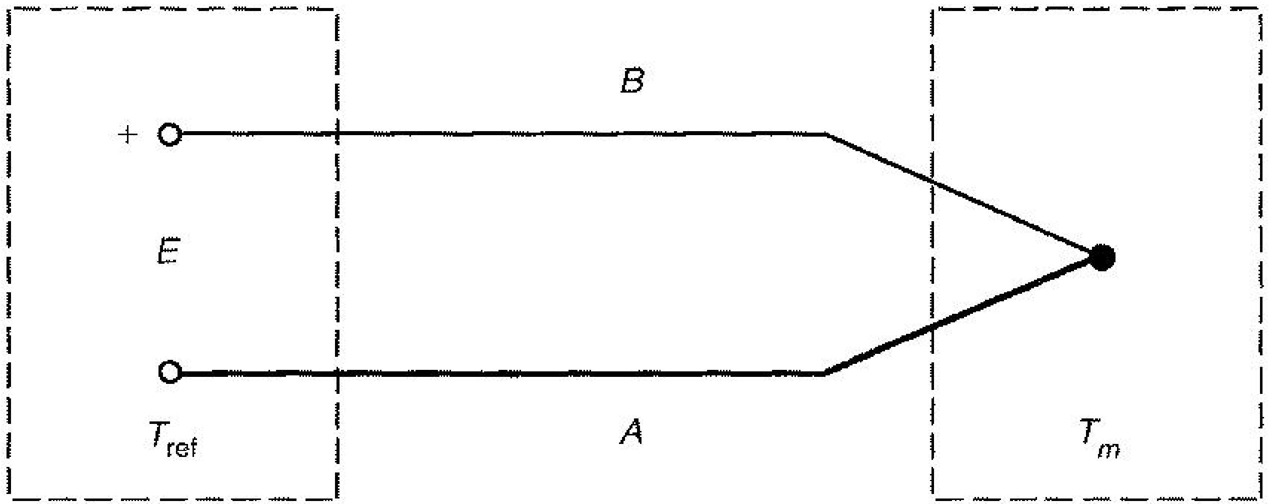


THE SEEBECK EFFECT

$$\mathcal{E}(T_2) - \mathcal{E}(T_1) = \int_{T_1}^{T_2} \sigma(T)\, dT$$



alpha is called Seebeck Coefficient



$$E = \int_{T_{ref}}^{T_m} \sigma_A \, dT + \int_{T_m}^{T_{ref}} \sigma_B \, dT$$

$$= [\mathcal{E}_A(T_m) - \mathcal{E}_A(T_{ref})] + [\mathcal{E}_B(T_{ref}) - \mathcal{E}_B(T_m)]$$

$$= [\mathcal{E}_A(T_m) - \mathcal{E}_B(T_m)] - [\mathcal{E}_A(T_{ref}) - \mathcal{E}_B(T_{ref})]$$

Define: relative Seebeck emf ->
(of materials A and B)

$$\mathcal{E}_{AB}(T) \equiv \mathcal{E}_A(T) - \mathcal{E}_B(T)$$

Then

$$E = \mathcal{E}_{AB}(T_m) - \mathcal{E}_{AB}(T_{ref})$$

Thermocouple

Voltage in millivolts

Reference = 0 deg C

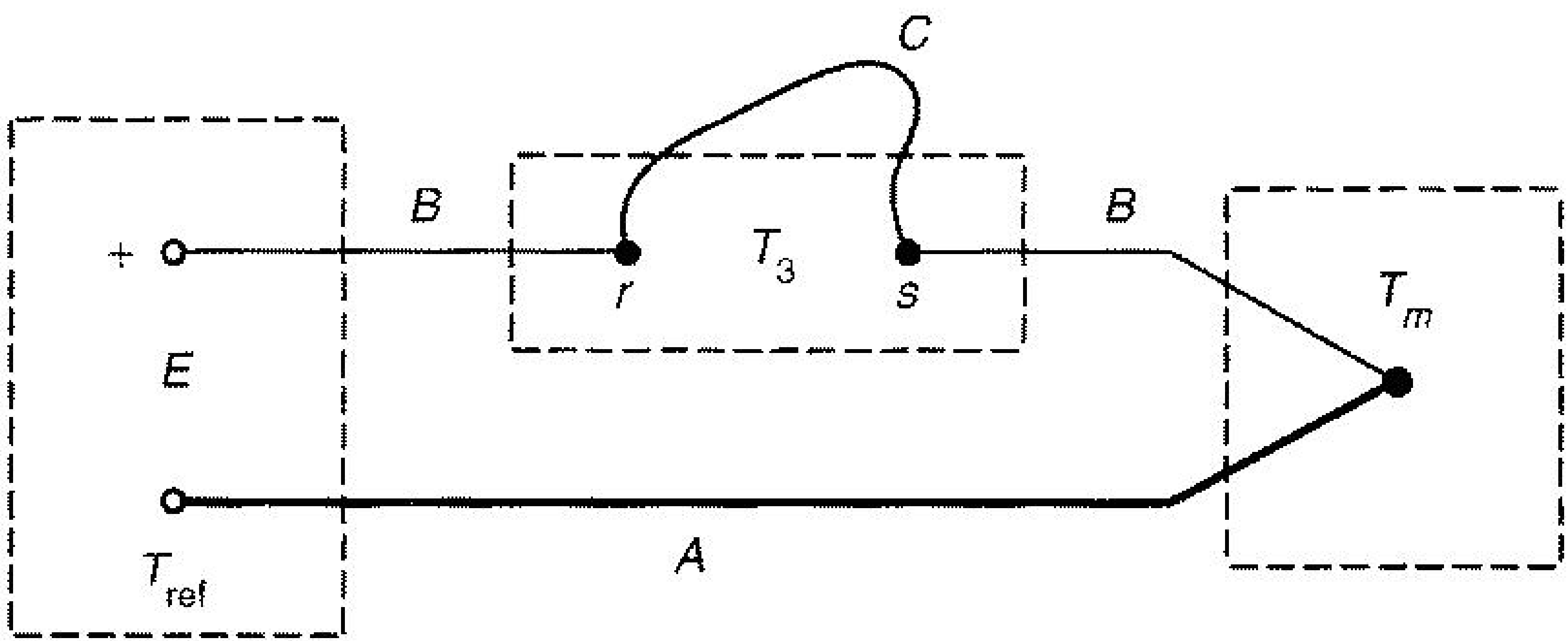
	Type K				
°C	0	5	10	15	20
−200	−5.891	−5.813	−5.730	−5.642	−5.550
−175	−5.454	−5.354	−5.250	−5.141	−5.029
−150	−4.913	−4.793	−4.669	−4.542	−4.411
−125	−4.276	−4.138	−3.997	−3.852	−3.705
−100	−3.554	−3.400	−3.243	−3.083	−2.920
−75	−2.755	−2.587	−2.416	−2.243	−2.067
−50	−1.889	−1.709	−1.527	−1.343	−1.156
−25	−0.968	−0.778	−0.586	−0.392	−0.197
0	0.000	0.198	0.397	0.597	0.798
25	1.000	1.203	1.407	1.612	1.817
50	2.023	2.230	2.437	2.644	2.851
75	3.059	3.267	3.474	3.682	3.889
100	4.096	4.303	4.509	4.715	4.920
125	5.124	5.328	5.532	5.735	5.937
150	6.138	6.340	6.540	6.741	6.941
175	7.140	7.340	7.540	7.739	7.939
200	8.139	8.338	8.539	8.739	8.940
225	9.141	9.343	9.545	9.747	9.950
250	10.153	10.357	10.561	10.766	10.971
275	11.176	11.382	11.588	11.795	12.002
300	12.209	12.416	12.624	12.832	13.040
325	13.248	13.457	13.665	13.875	14.084
350	14.293	14.503	14.713	14.923	15.133
375	15.343	15.554	15.764	15.975	16.186

Law of intermediate metals

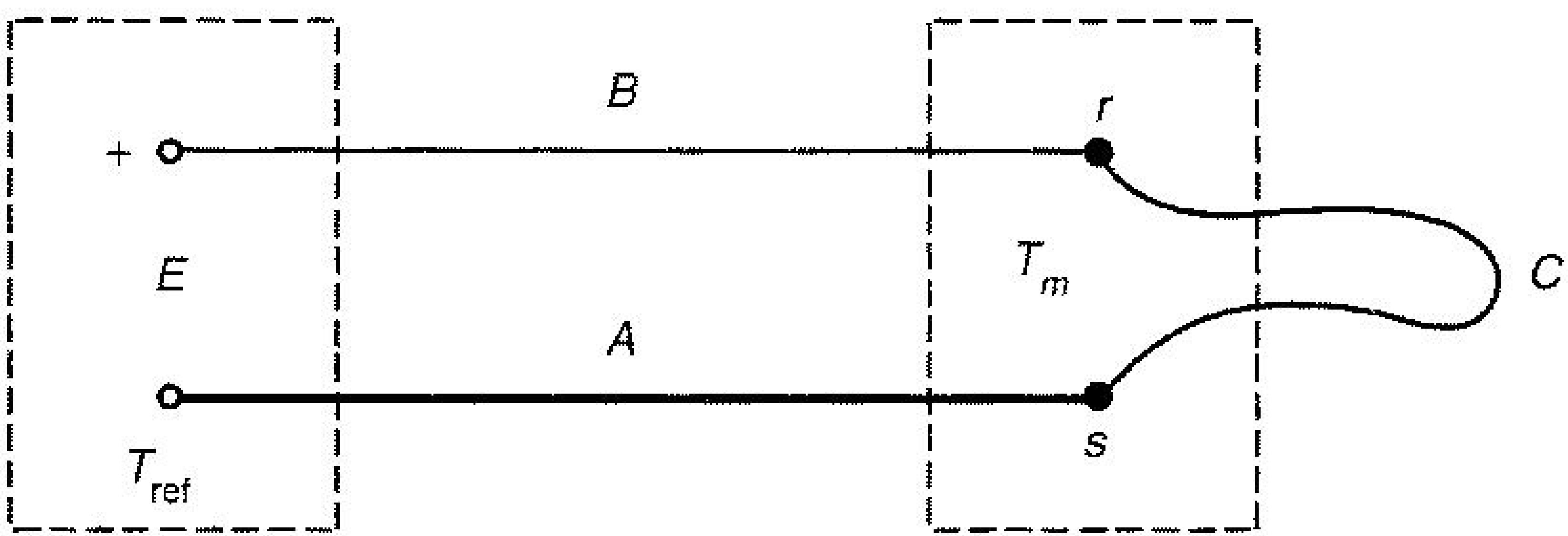
Insertion of an intermediate metal into a thermocouple circuit will not affect the net emf -

provided that the two junctions introduced by the third metal are at identical temperatures

(a)

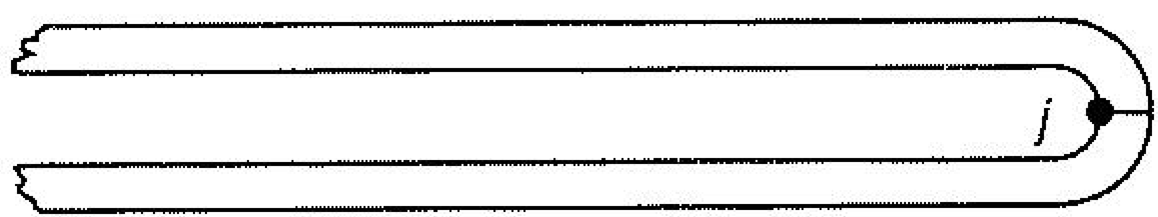


(b)



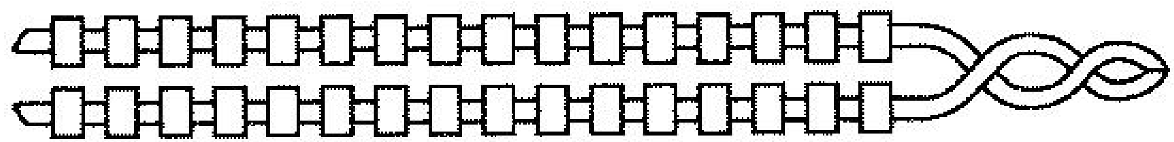
For gas, electric, and arc welding

For resistance welding, large wires

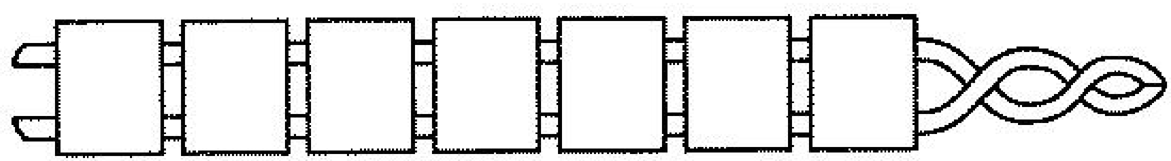


For forming noble-metal wires for electric arc welding

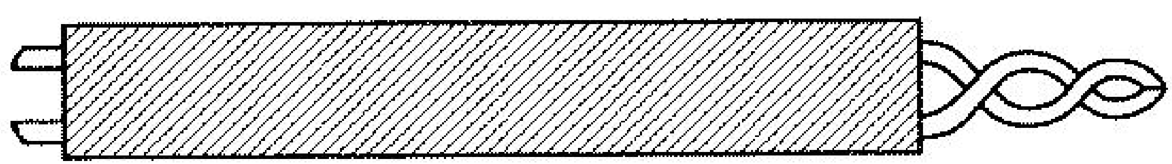
Bare element



Element with bead insulators



Element with double-bore insulators



Element with ceramic-tubing insulators

Termocouple voltages - in millivolts

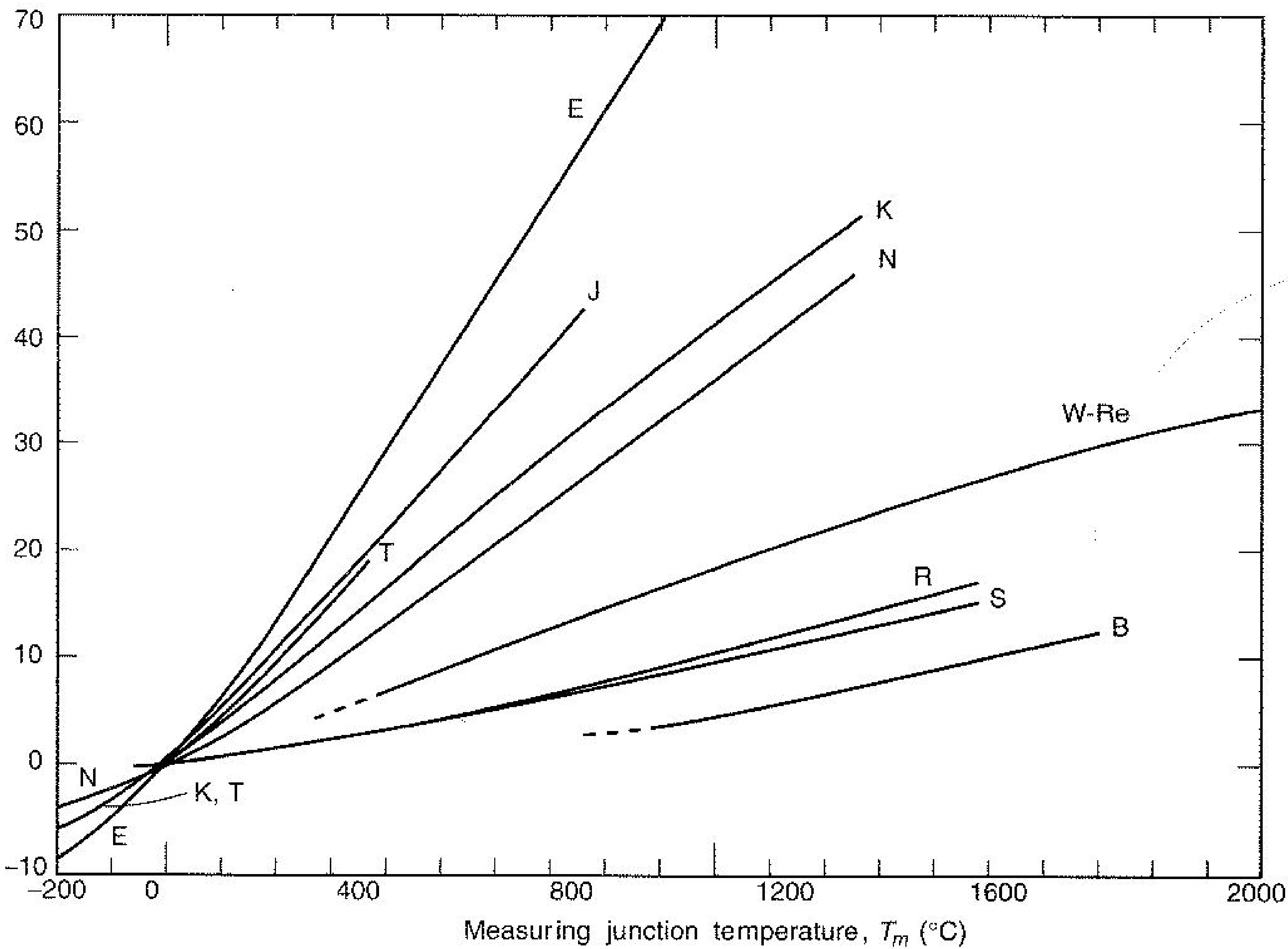
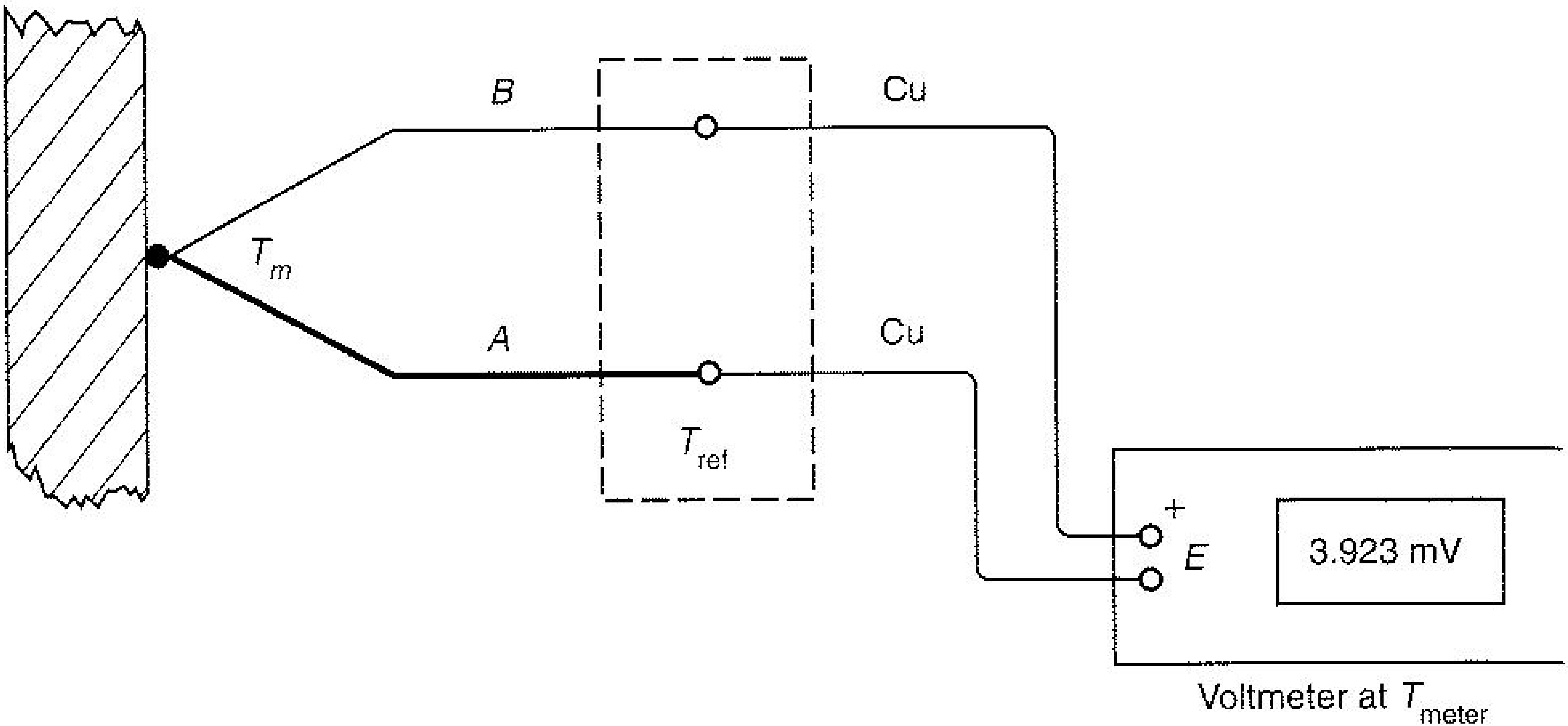
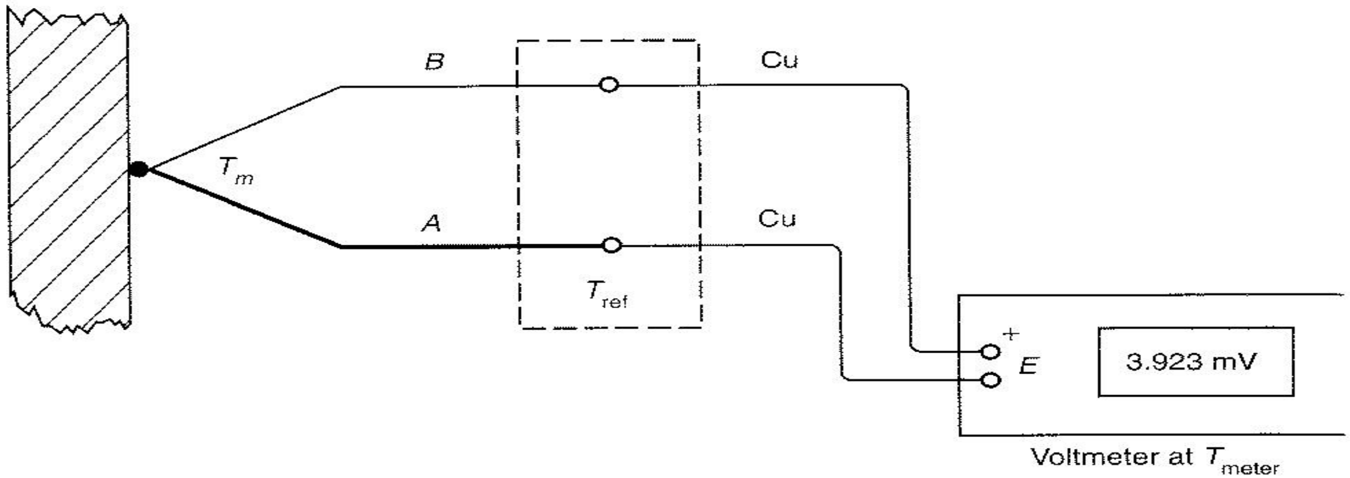


TABLE 16.4: Thermocouple Voltage E in Millivolts versus Temperature T_m for Reference Junctions at $T_{ref} = 0°C$. Values Are Limited to the Recommended Range of Use [11]

	Thermocouple Type				
Temperature °C (°F)	**Chromel vs. Constantan E**	**Iron vs. Constantan J**	**Chromel vs. Alumel K**	**Pt/10% Rh vs. Platinum S**	**Copper vs. Constantan T**
−200 (−328)	−8.825		−5.891		−5.603
−150 (−238)	−7.279		−4.913		−4.648
−100 (−148)	−5.237		−3.554		−3.379
−50 (−58)	−2.787		−1.889	−0.236	−1.819
0 (32)	0.000	0.000	0.000	0.000	0.000
50 (122)	3.048	2.585	2.023	0.299	2.036
100 (212)	6.319	5.269	4.096	0.646	4.279
150 (302)	9.789	8.010	6.138	1.029	6.704
200 (392)	13.421	10.779	8.139	1.441	9.288
300 (572)	21.036	16.327	12.209	2.323	14.862
400 (752)	28.946	21.848	16.397	3.259	
600 (1112)	45.093	33.102	24.906	5.239	
800 (1472)	61.017		33.275	7.345	
1000 (1832)			41.276	9.587	
1200 (2192)			48.838	11.951	
1400 (2552)				14.373	

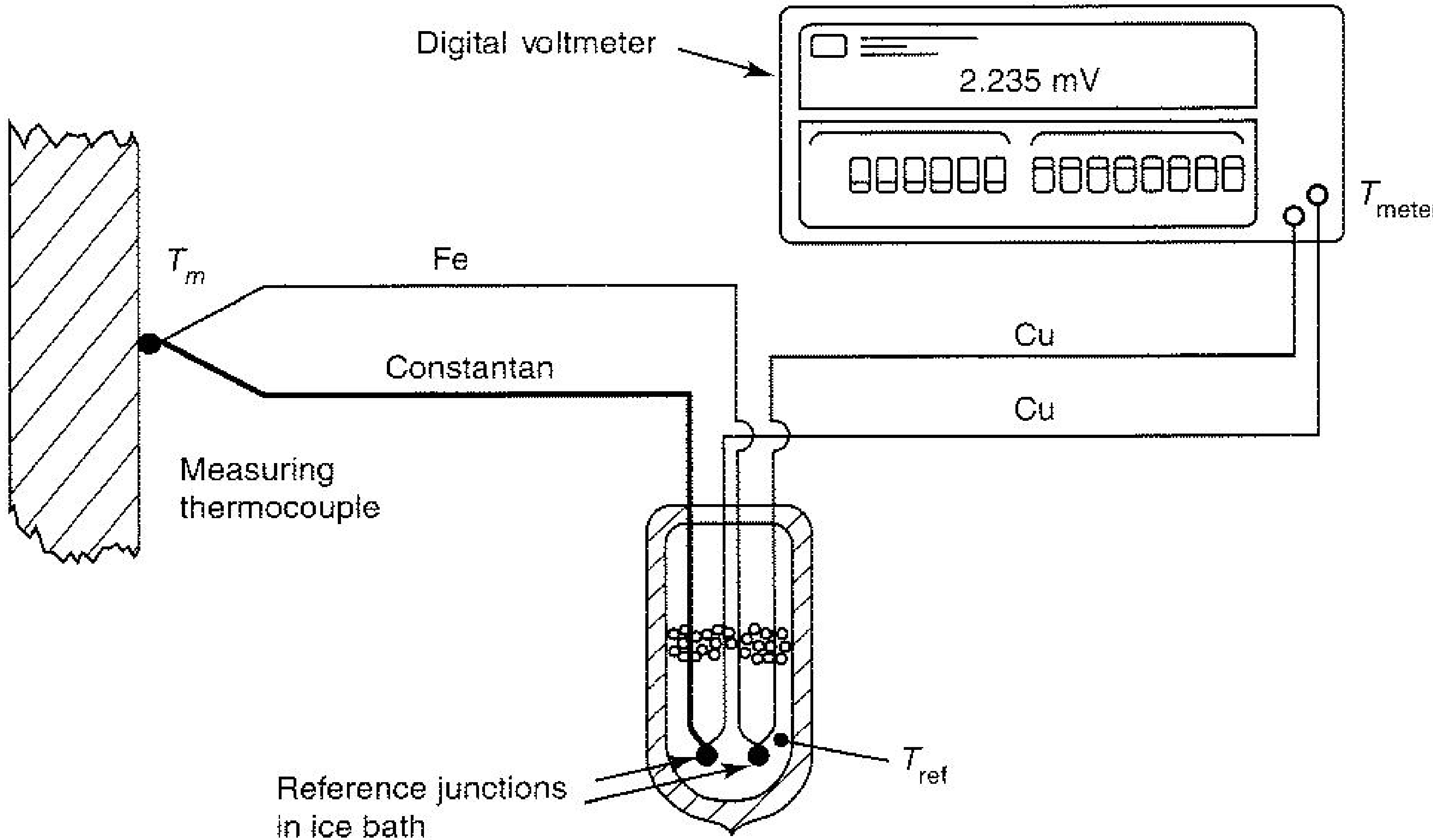


B
Cu
T_m
A
Cu
T_{ref}
+
E
3.923 mV
Voltmeter at T_{meter}



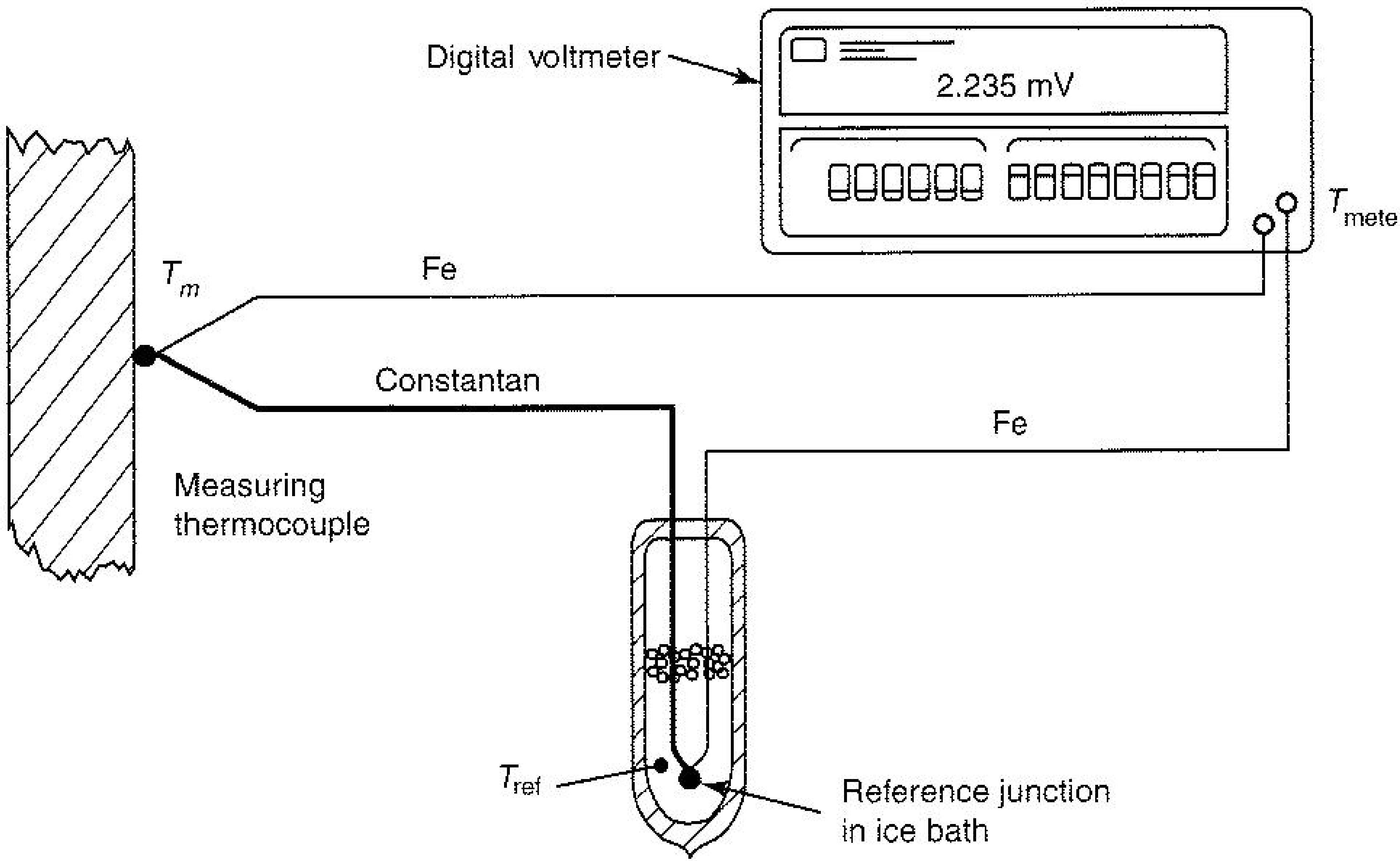
$$
\begin{aligned}
E &= [\mathcal{E}_{Cu}(T_{ref}) - \mathcal{E}_{Cu}(T_{meter})] + [\mathcal{E}_A(T_m) - \mathcal{E}_A(T_{ref})] \\
&\quad + [\mathcal{E}_B(T_{ref}) - \mathcal{E}_B(T_m)] + [\mathcal{E}_{Cu}(T_{meter}) - \mathcal{E}_{Cu}(T_{ref})] \\
&= \mathcal{E}_{AB}(T_m) - \mathcal{E}_{AB}(T_{ref})
\end{aligned}
$$

(a)



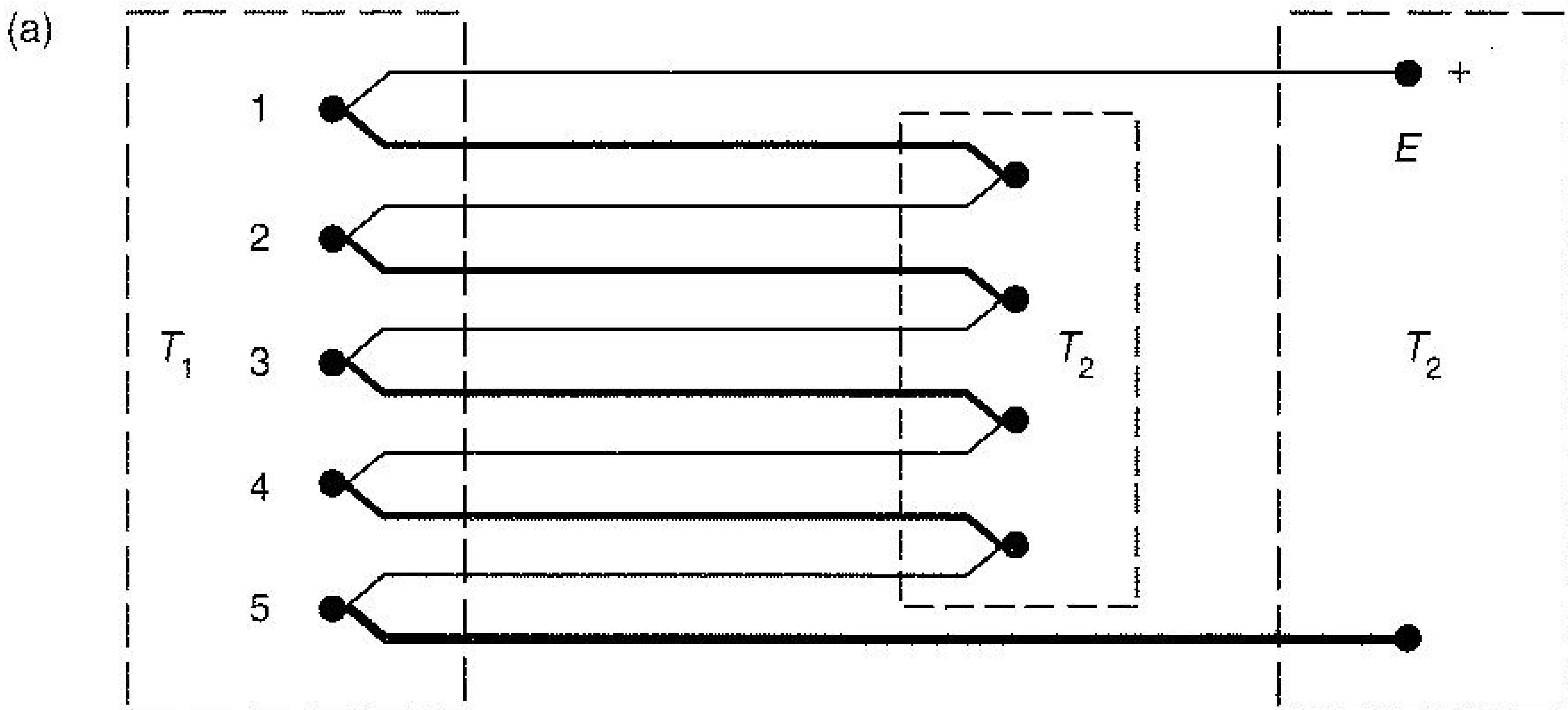
$$E = \mathcal{E}_{\mathrm{FeCn}}(T_m) - \mathcal{E}_{\mathrm{FeCn}}(0^\circ\mathrm{C})$$

(b)



Digital voltmeter
2.235 mV
T_{meter}
T_m
Fe
Constantan
Fe
Measuring thermocouple
T_{ref}
Reference junction in ice bath

Thermocouples can be connected in series
Increases output voltage and averages



Thermocouples can be connected in parallel
Creates an average of T1, T2, T3, T4