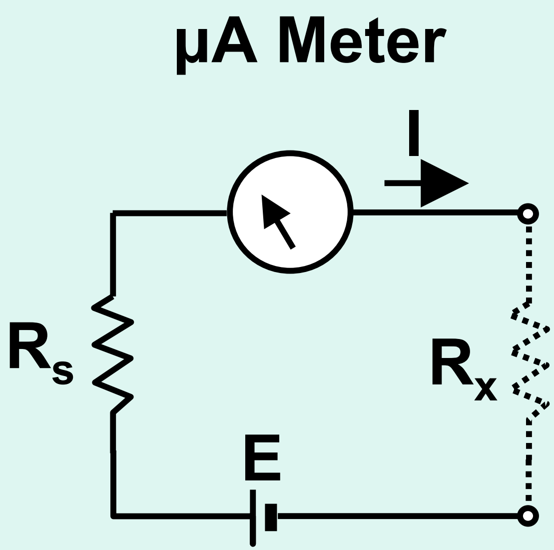
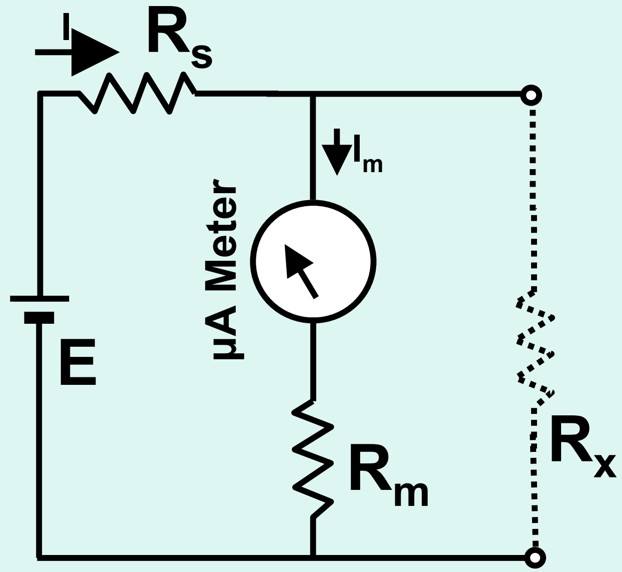
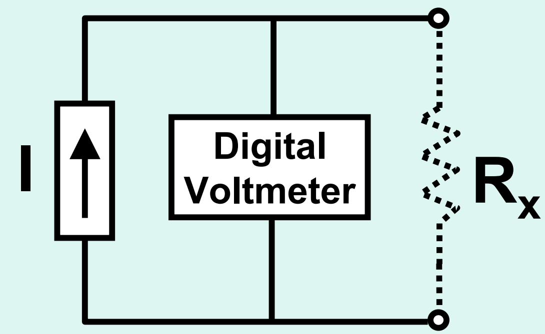
Ohmmeters



Series



Shunt



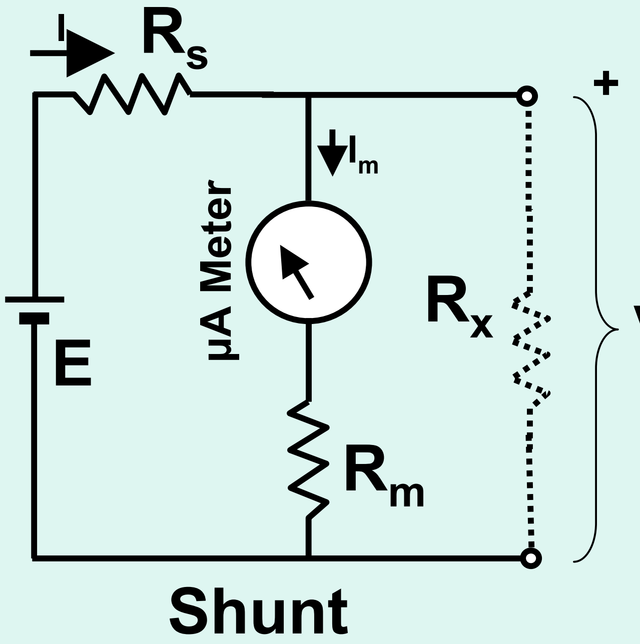
Digital

$$I = \frac{E}{R_s + R_x}$$

$$I = \frac{R_x}{R_s(R_m + R_x) + R_m R_x}\mathbf{E}$$

$$V = IR_x$$

Shunt Ohmmeter



$$\text{When } R_x = \infty$$

$$I_m = \frac{E}{R_s + R_m}$$

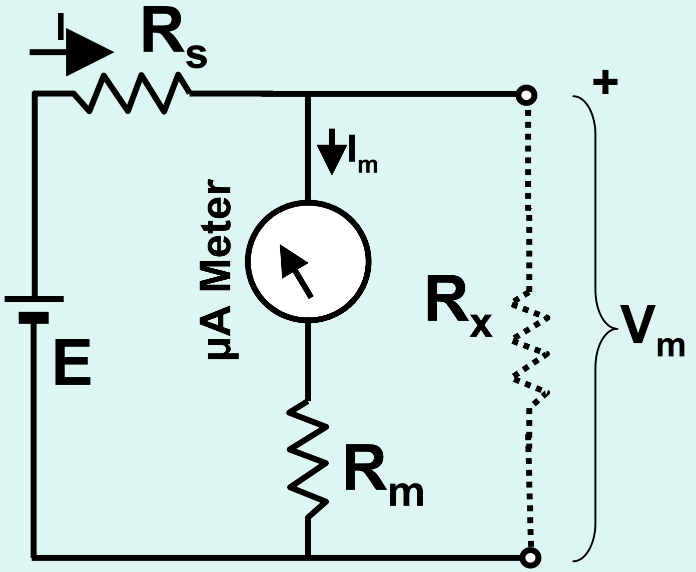
$$v_m = \frac{R_m \| R_s}{R_s + R_m \| R_s} E$$

$$v_m = \frac{\dfrac{R_m R_x}{R_m + R_x}}{R_s + \dfrac{R_m R_x}{R_m + R_x}} E = \frac{R_m R_x}{R_s (R_m + R_x) + R_m R_x} E$$

$$I_m = \frac{v_m}{R_m} = \frac{R_x}{R_s (R_m + R_x) + R_m R_x} E$$

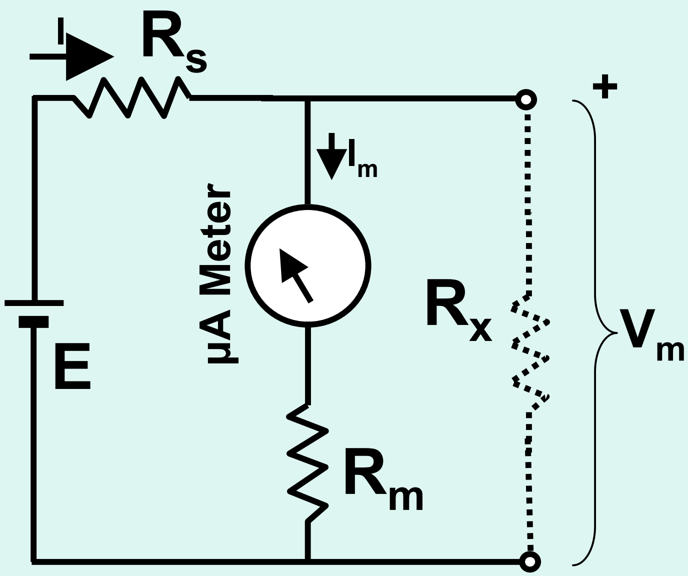
Sample Problem

Complete the design of the shunt ohmmeter and generate a calibration plot when R_m=1000 Ω and the meter has a full-scale reading of 100 µA.



Sample Problem

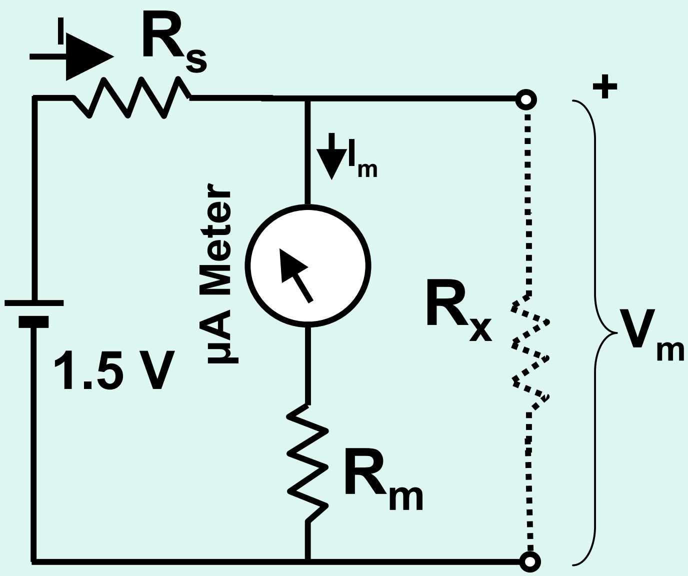
Complete the design of the shunt ohmmeter and generate a calibration plot when R_m=1000 Ω and the meter has a full-scale reading of 100 µA.



First step: Determine R_s

Sample Problem

Complete the design of the shunt ohmmeter and generate a calibration plot when R_m=1000 Ω and the meter has a full-scale reading of 100 μA.



First step: Determine R_s

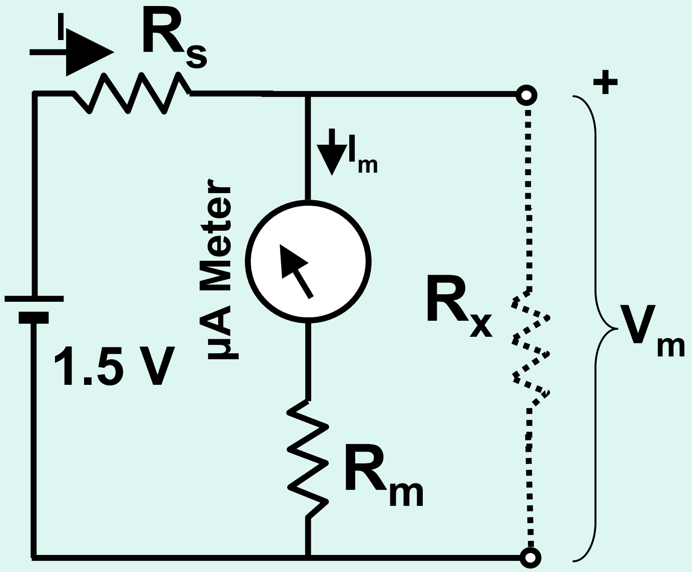
When R_x is infinite, I = I_m = 100 μA.

$$R_s + R_m = \frac{E}{I_{m_{\text{full-scale}}}} = \frac{1.5\text{V}}{100\,\mu\text{A}} = 15{,}000\Omega$$

$$R_s = 15{,}000\Omega - 1{,}000\Omega = 14{,}000\Omega$$

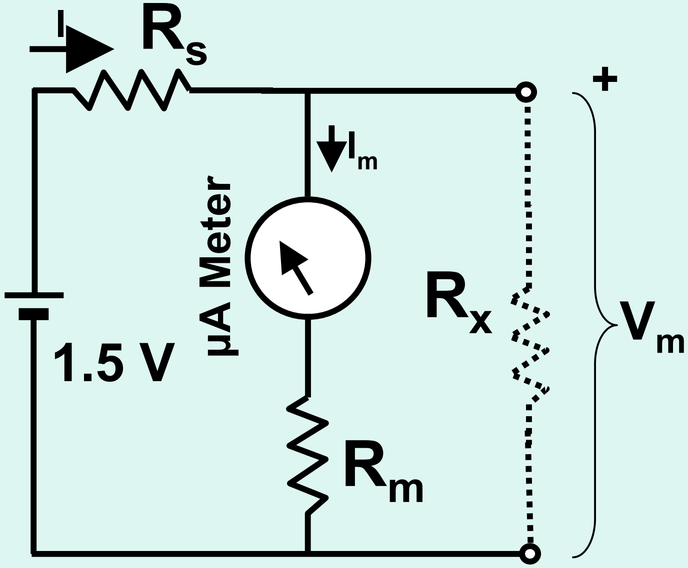
Sample Problem

Second Step: Generate a calibration curve



Sample Problem

Second Step: Generate a calibration curve

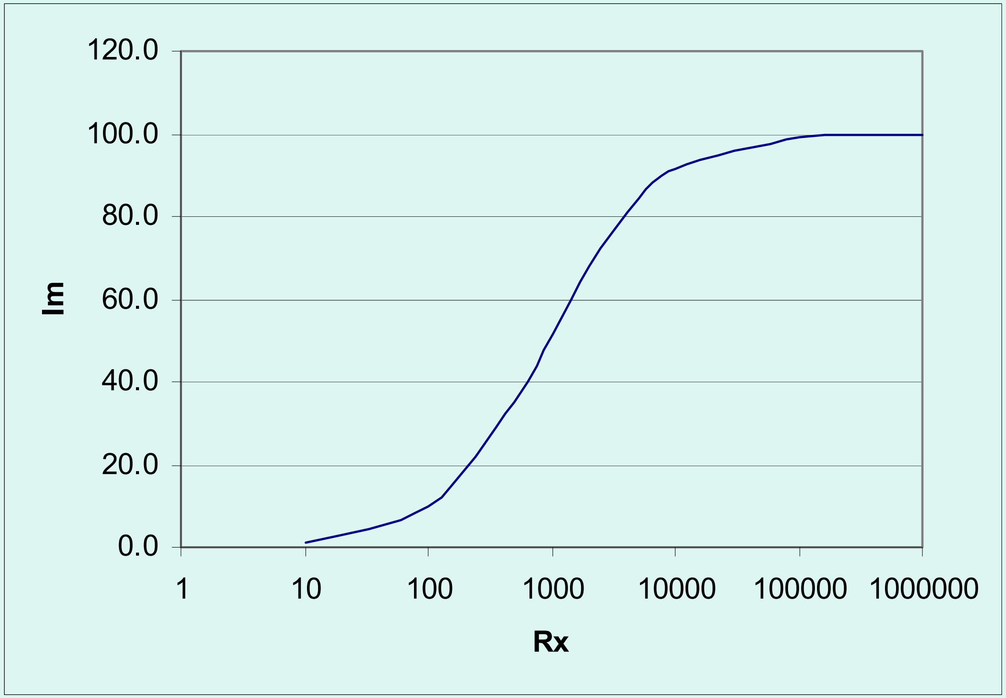


Make a spread sheet giving the meter current I_m as a function of selected values of the unknown resistance, R_x

$$I = \frac{R_x}{R_s(R_m + R_x) + R_m R_x} \mathbf{E}$$

Sample Problem

R_x	I_m
0	0.0
10	1.1
100	9.7
500	34.9
1000	51.7
2000	68.2
5000	84.3
10000	91.5
100000	99.1
500000	99.8
1000000	99.9



Other Displacement Sensors

- Variable capacitance
- Linear variable differential transformer (LVDT)
- Variable inductance
- Mutual inductance
- Ultrasound transit time

Temperature Measurement Definitions

- **Heat –** Form of energy of a body as an effect of their molecular motion **Q**
- **Heat Flux –** Transport of thermal energy $\frac{dQ}{dt} = \dot{Q}$
- **Temperature –** The degree of heat in a body as measured on a defined scale

Electrical Equivalent

- **Charge Q**
- **Current** $I = \frac{dQ}{dt}$
- **Voltage V**

Temperature Measurement More Definitions

Electrical Equivalent

- **Heat Capacity –** The amount of heat to increase the temperature of a body by one unit

$$Q = C\Delta T$$

- **Capacitance**

- **Specific Heat –** Heat capacity per unit mass

$$C_s = \frac{C}{m}$$

- **Thermal Resistance –** A constant relating heat flux and temperature difference

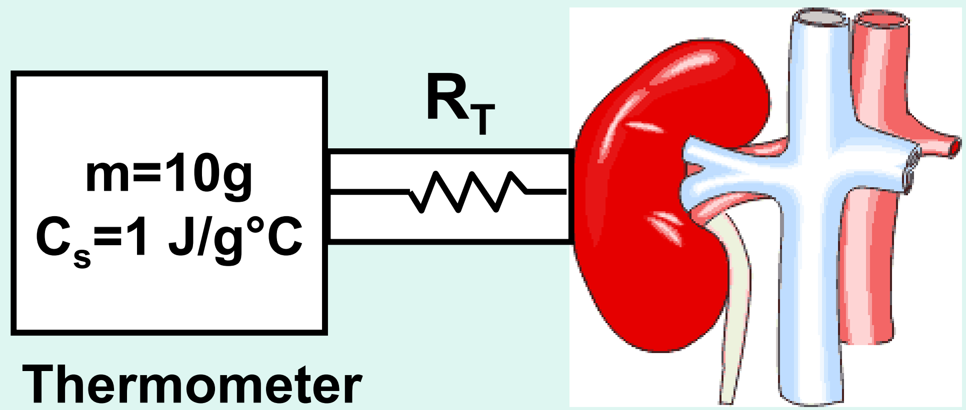
$$\Delta T = R_T \dot{Q}$$

- **Resistance**

$$\Delta V = RI$$

Sample Problem

How much will a thermometer whose initial temperature is 20°C affect the temperature of the kidney?



R_T=5°Cs/J

m=50g
C_s=4 J/g°C

Approach: convert to an equivalent electrical circuit

Heat capacity

$$C_k = 50\text{g} \bullet 4\ \text{J}/\text{g}^\circ\text{C} = 200\ \text{J}/^\circ\text{C}$$

$$C_T = 10\text{g} \bullet 1\ \text{J}/\text{g}^\circ\text{C} = 10\ \text{J}/^\circ\text{C}$$

$$C_{total} = 200\ \text{J}/^\circ\text{C} + 10\ \text{J}/^\circ\text{C} = 210\ \text{J}/^\circ\text{C}$$

Heat

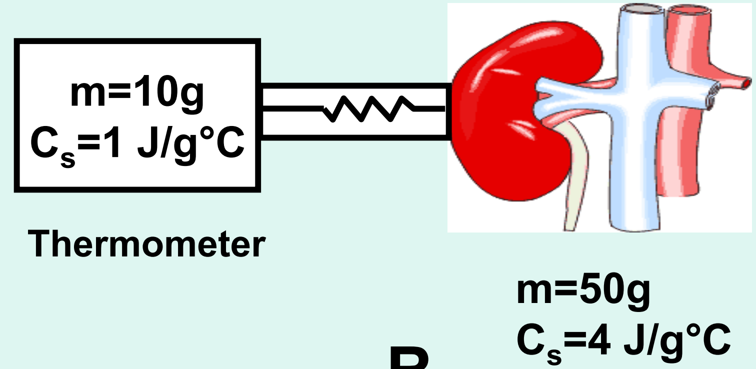
$$Q_k = 200\ \text{J}/^\circ\text{C} \bullet 37^\circ\text{C} = 7{,}400\text{J}$$

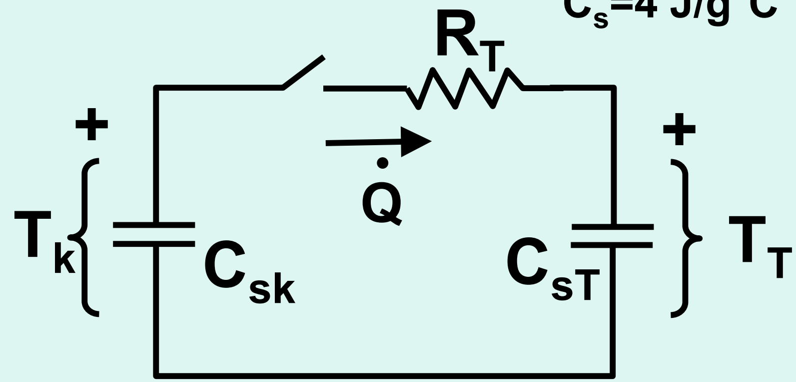
$$Q_T = 10\ \text{J}/^\circ\text{C} \bullet 20^\circ\text{C} = 200\text{J}$$

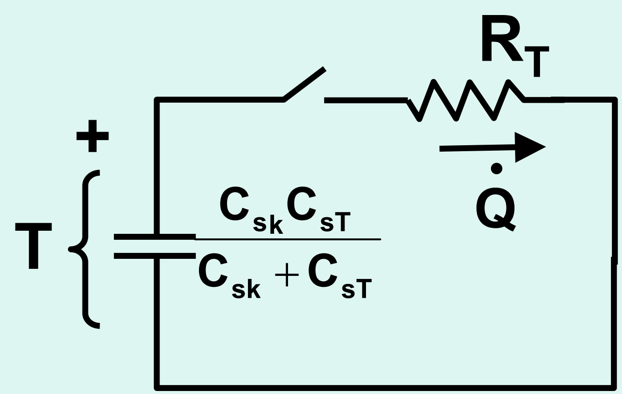
$$Q_{total} = 7{,}600\text{J}$$

Final Temperature of kidney and thermometer

$$T = \frac{Q_{total}}{C_{total}} = \frac{7{,}600\text{J}}{210\ \text{J}/^\circ\text{C}} = 36.2^\circ\text{C}$$







Plot the Thermometer's Response

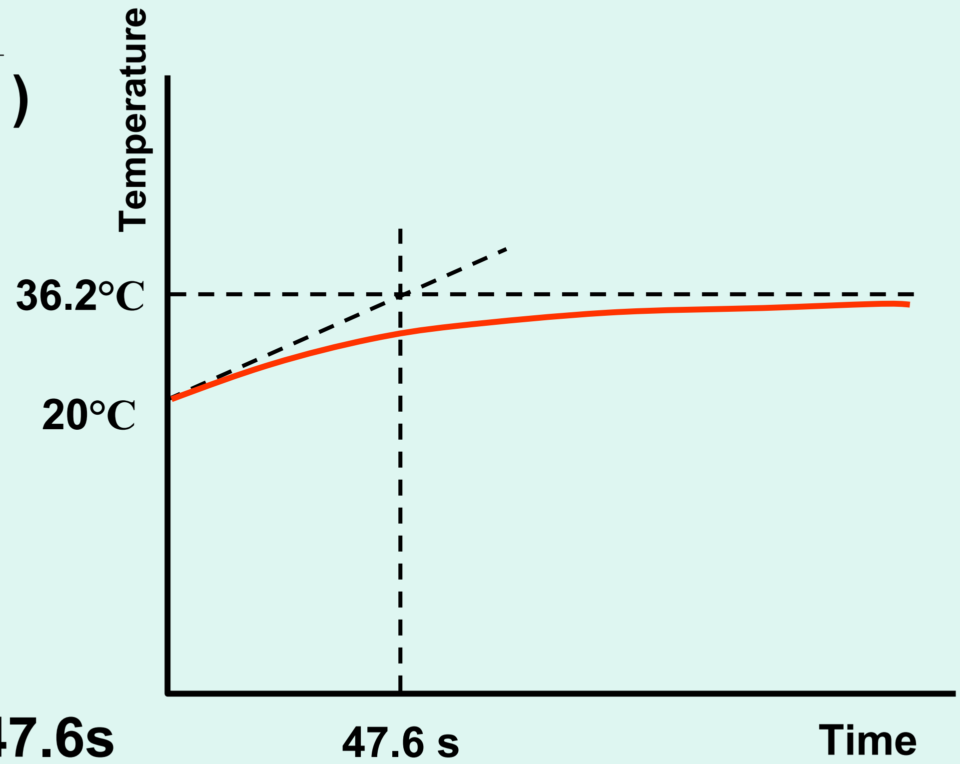
First-order dynamic system with response in the form

$$T(t) = 20°C + 16.2°C\left(1 - e^{\frac{-t}{R_T C_{total}}}\right)$$

Time constant

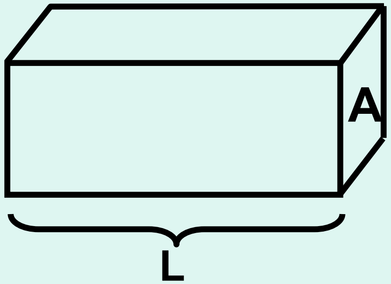
$$C_{total} = \frac{C_k \bullet C_t}{C_k + C_t}$$

$$\tau = R_T C_{total} = 5\frac{°Cs}{J} \bullet 9.52\frac{J}{°C} = 47.6s$$



Resistance Temperature Detector (RTD)

- **Electrical resistance of an electrical conductor is a function of temperature**



$$R = \rho \frac{L}{A}$$

ρ is temperature dependent therefore resistance will be temperature dependent

$$R_T = R_0\left[1 + \alpha(T - T_0)\right]$$

Where α is the temperature coefficient of resistance for the material

Resistance Temperature Detector (RTD)

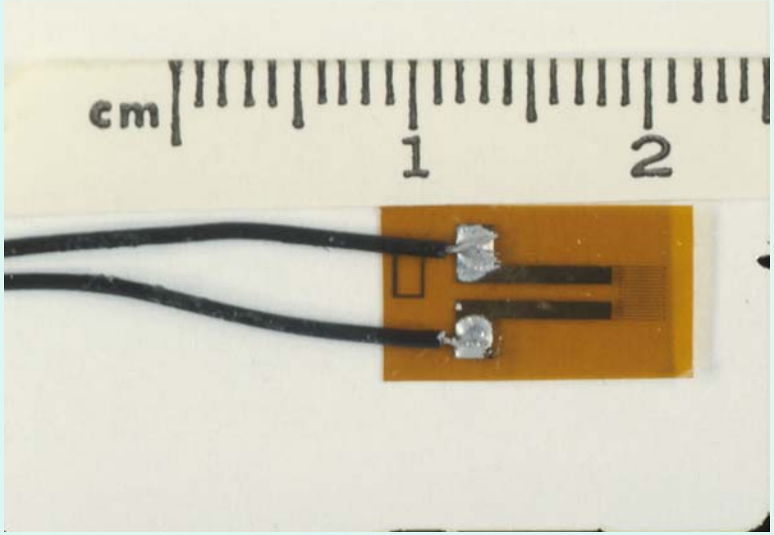
Examples of α

Material	α (°C^{-1})
Gold	0.0040
Platinum	0.00392
Silver	0.0041
Nickel	0.0067
Nichrome	0.0004
Manganin	0.00001

Resistance Temperature Detector (RTD)

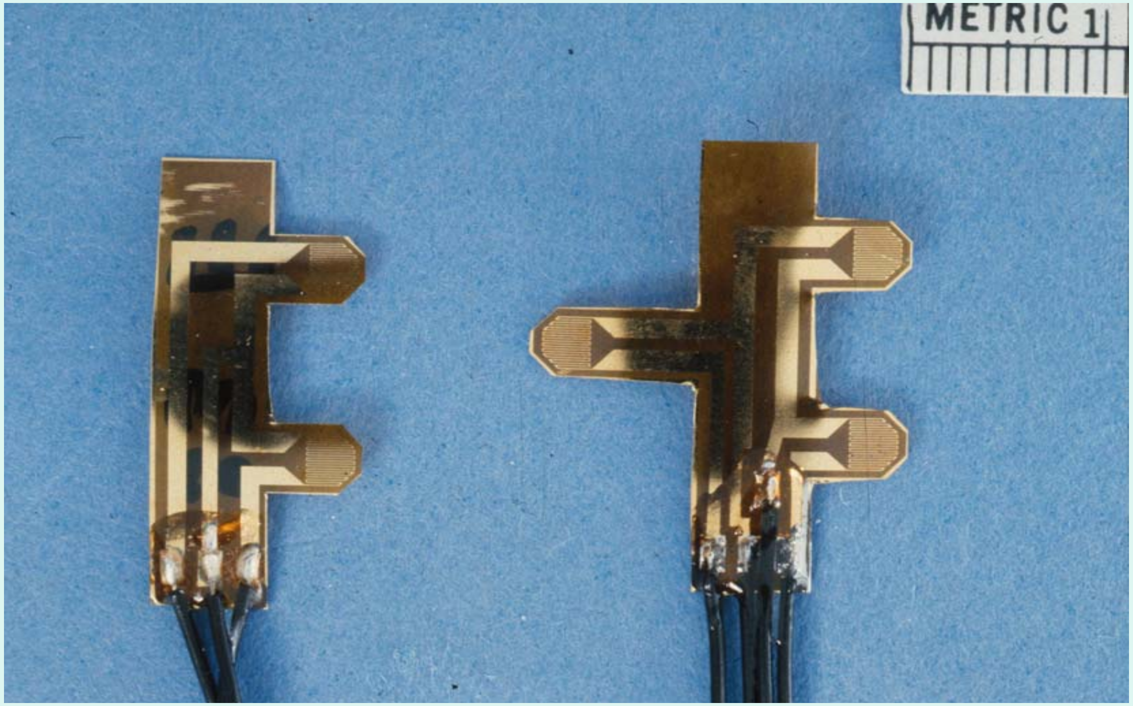
Examples

Industrial Sensors



Microfabricated Sensor

Thin-Film Gold Temperature Sensor



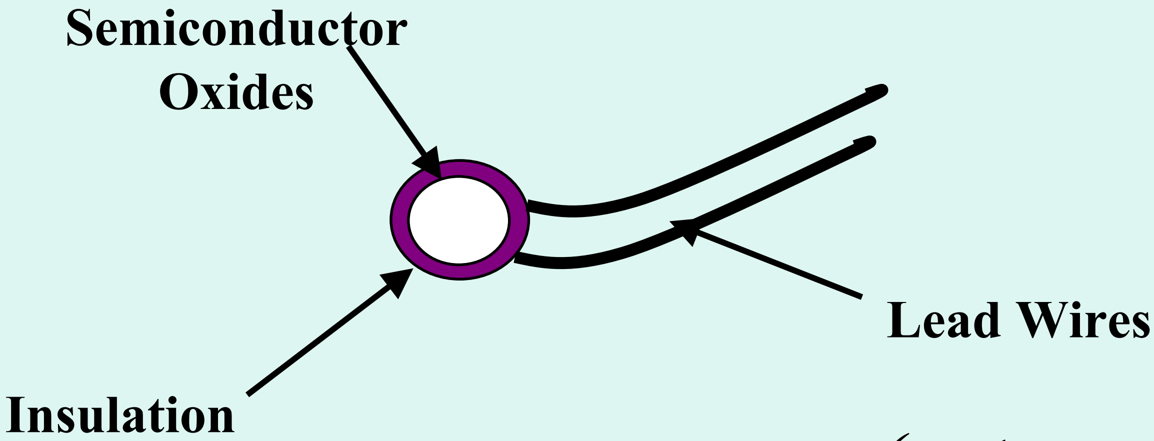
Nasal Oral/Nasal

In place on an infant

$$R = R_0\left(1 + \alpha\left(T - T_0\right)\right)$$

R_0 is the resistance at temperature T_0
α Is the temperature coefficient of resistance

Thermistor



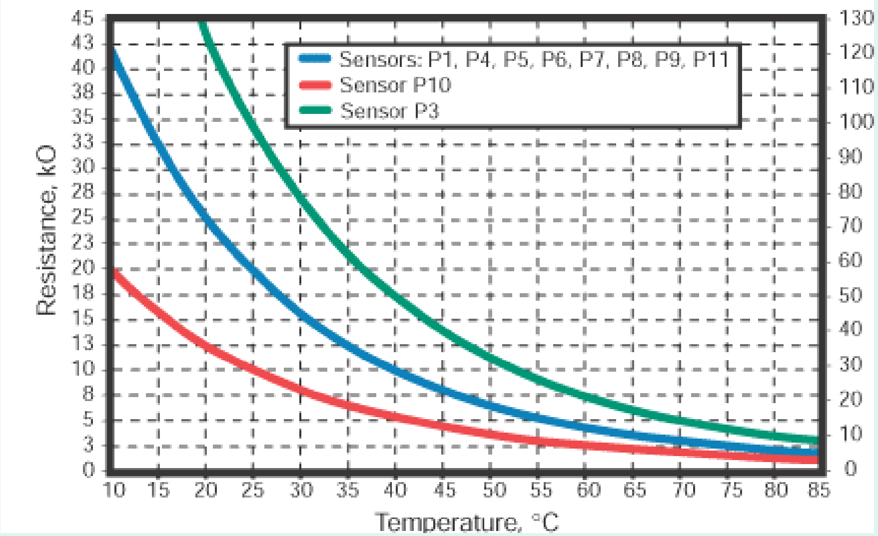
- **High sensitivity**
- **Inexpensive**
- **Non-linear**
- **Moderate stability**

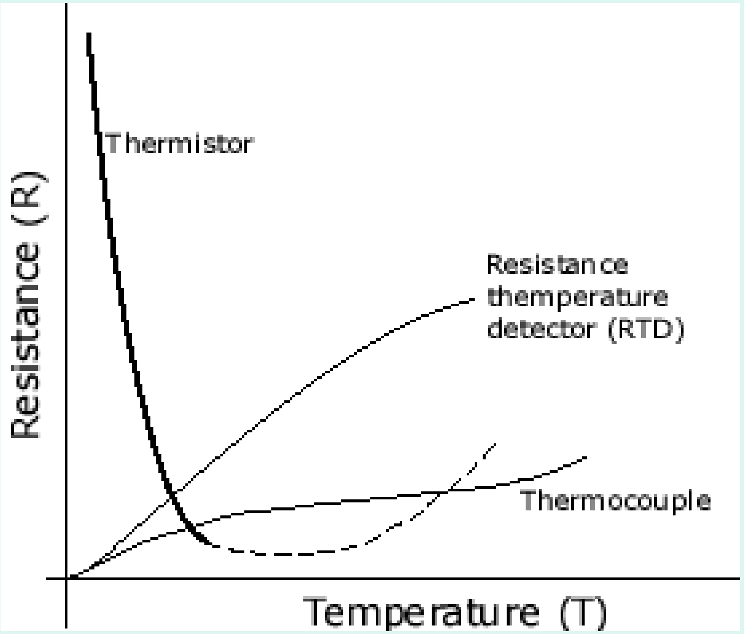
$$R = R_0 \exp\left(\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right)$$

R_0 is the resistance at absolute temperature T_0

β Is a constant

Thermistor





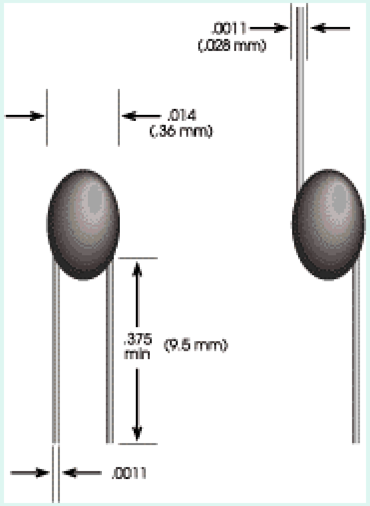
Effective temperature coefficient of about 5%/°C at body temperature (37°C)

Compare with RTD

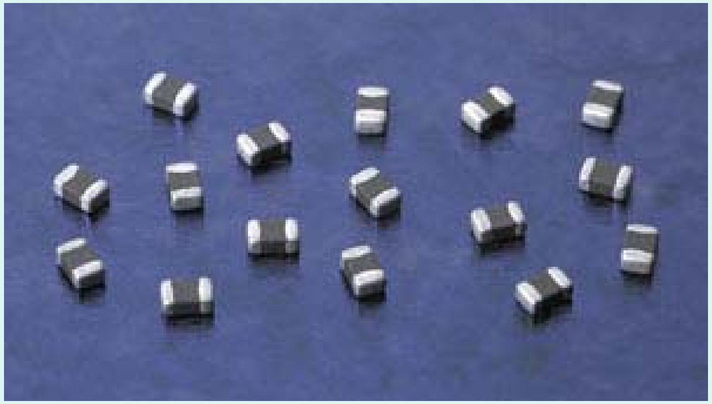
Commercial Thermistors

Disk

Probes

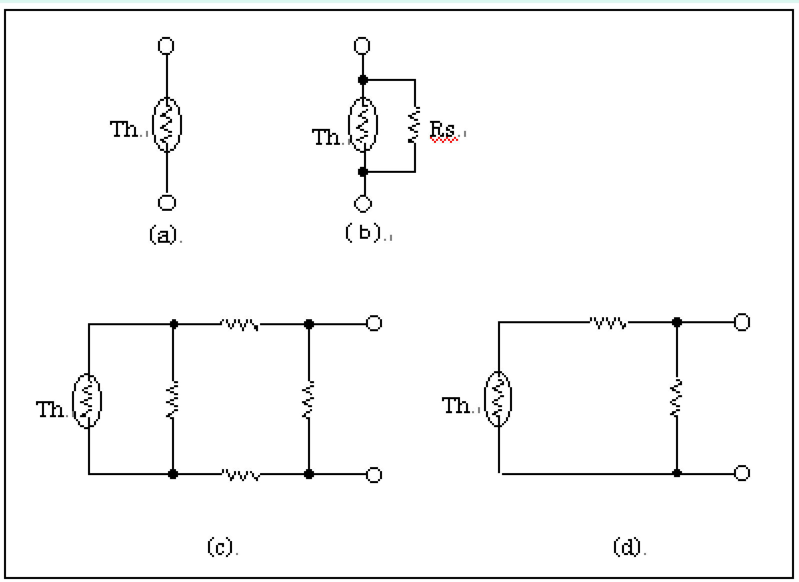


Bead

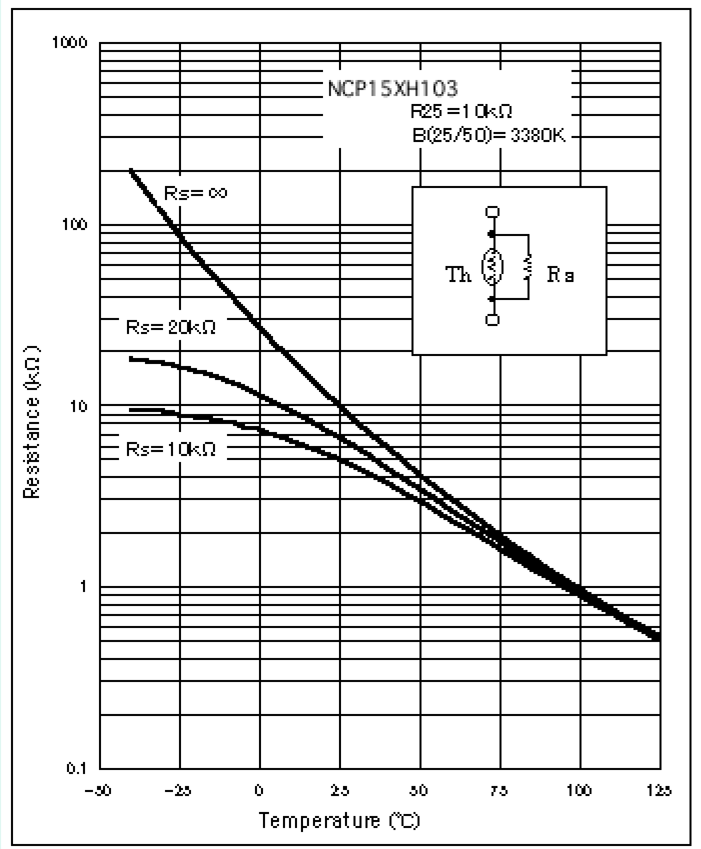


Chip

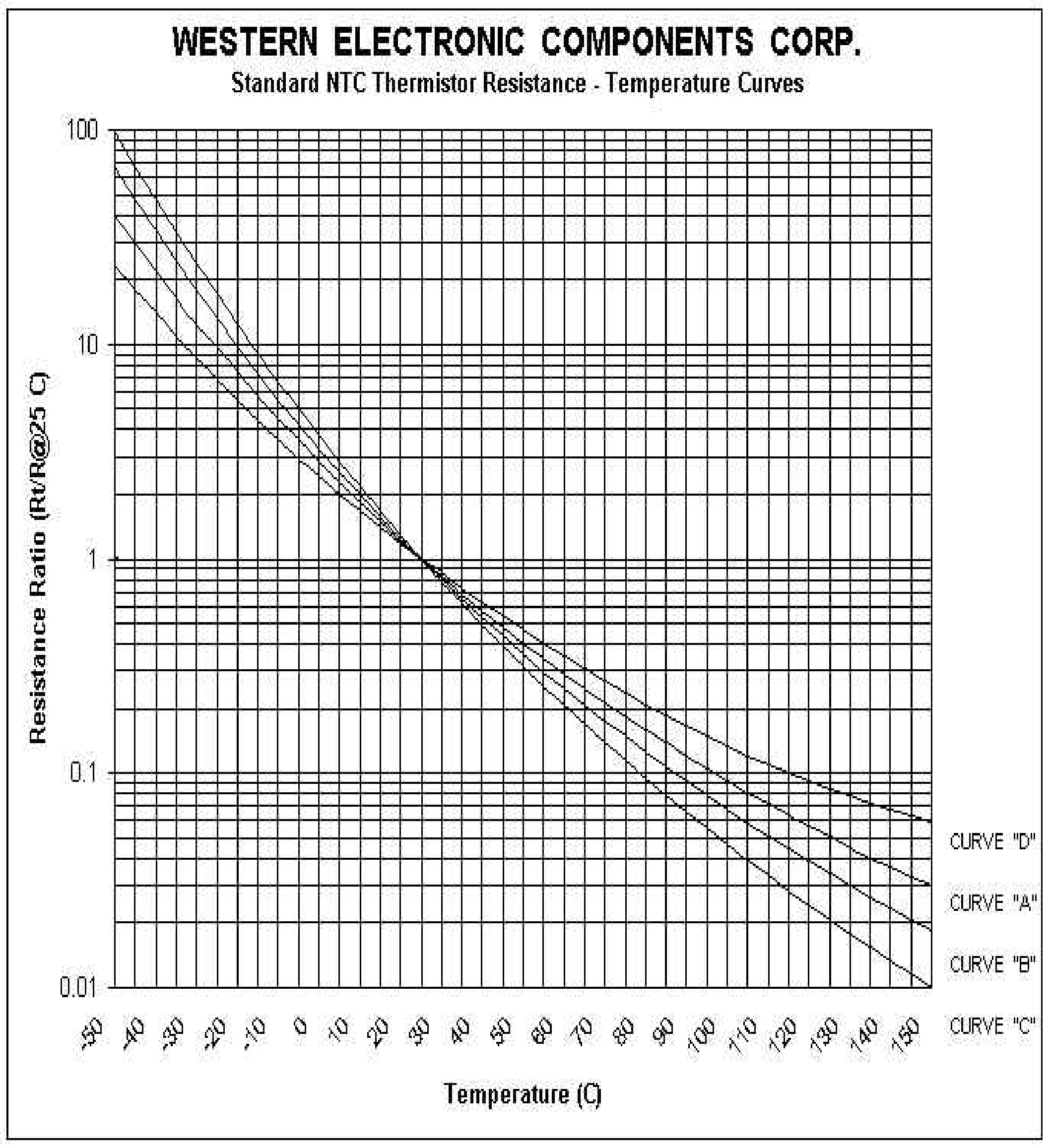
Linearizing Thermistor Characteristics



Linearizing Circuits



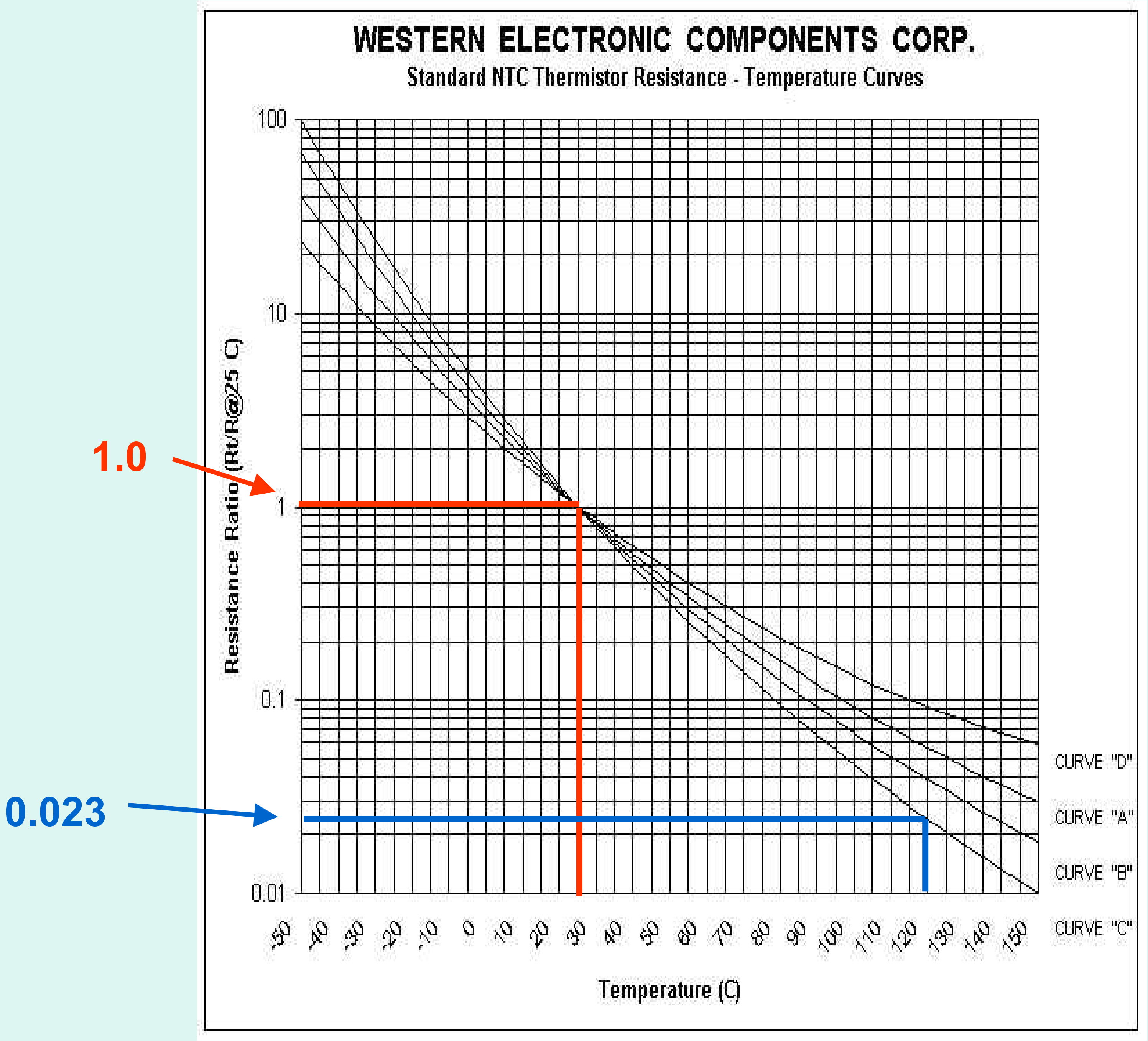
Standard Thermistor Curves



Sample Problem

A thermistor with the "curve C" characteristic is to be used in an autoclave sterilizer that sterilizes at a temperature of 120°C. When the autoclave is not operating, the thermistor resistance is 2,000 Ω at room temperature of 25°C. What is its resistance at the autoclave's operating temperature?

First step: use the standard thermistor curve C to determine the resistance ratio between the two temperatures

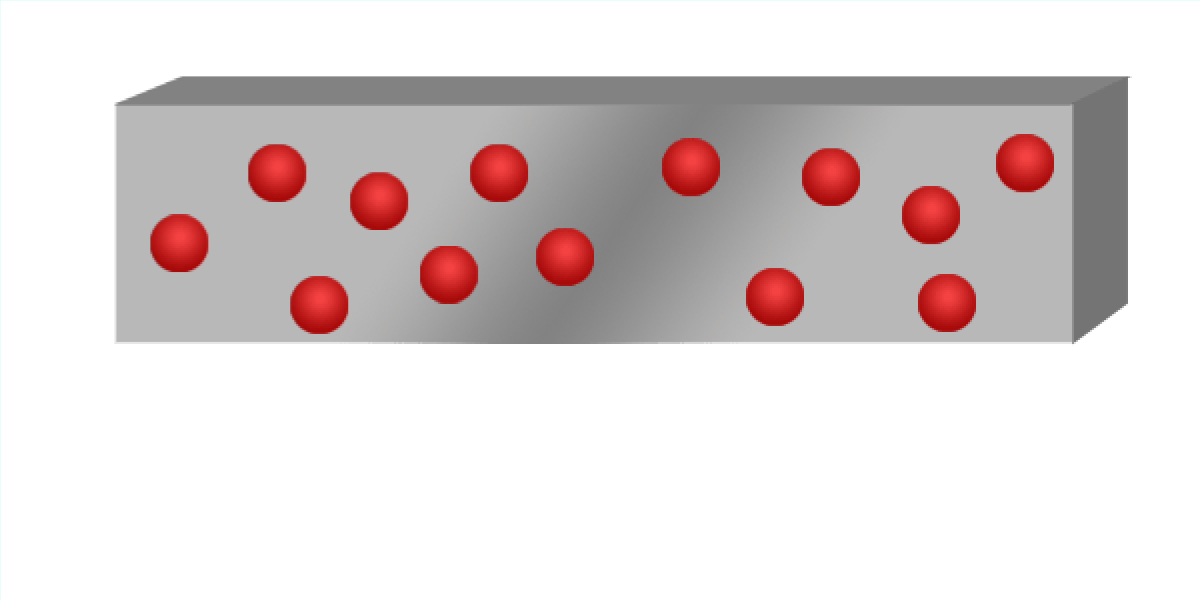


WESTERN ELECTRONIC COMPONENTS CORP.
Standard NTC Thermistor Resistance - Temperature Curves
Resistance Ratio (Rt/R@25 C)
100
10
1
0.1
0.01
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Temperature (C)
CURVE "D"
CURVE "A"
CURVE "B"
CURVE "C"
1.0
0.023

$$\text{Resistance ratio} = \frac{R_{120°C}}{R_{25°C}} = 0.023$$

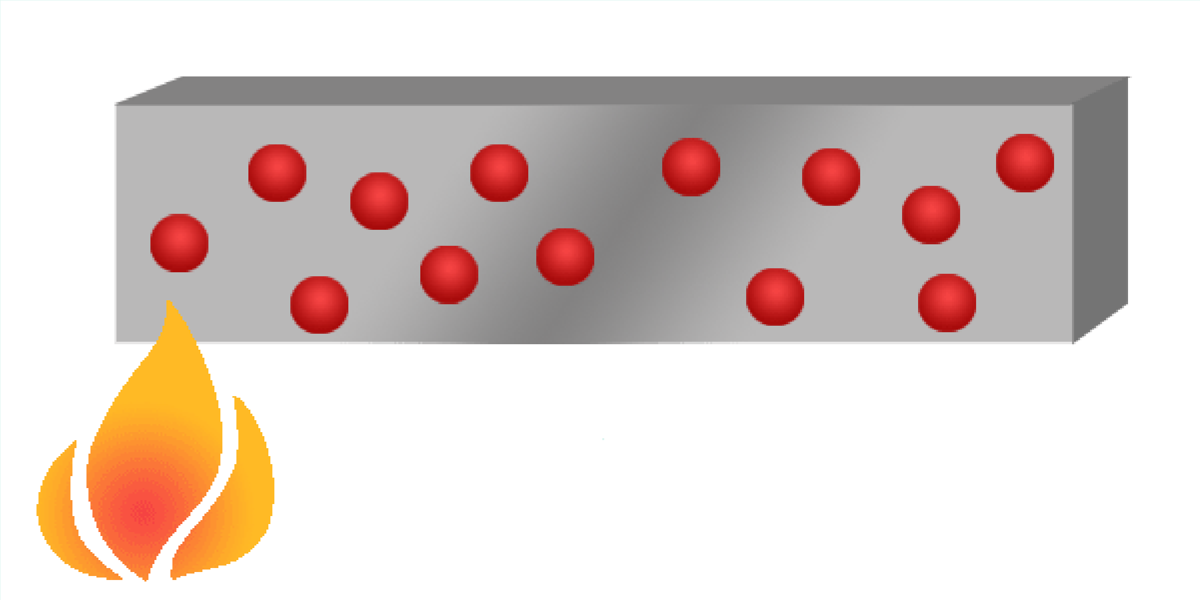
$$R_{120°C} = 0.023 \times 2{,}000\ \Omega = 46\ \Omega$$

Thermocouple



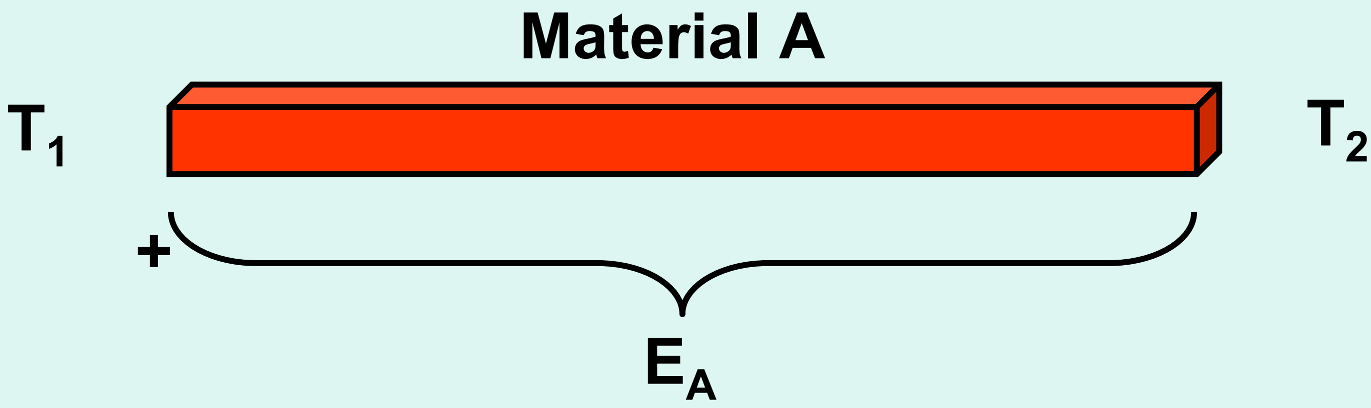
Free electrons in a metal at a temperature greater than absolute zero will have a kinetic energy associated with the metal's temperature.

Thermocouple



When one end of the metal is heated, the electrons at that end have a higher energy than those at the cooler end and there is a pressure for them to move to the lower temperature end. In other words, a voltage is developed between the hot and the cold ends.

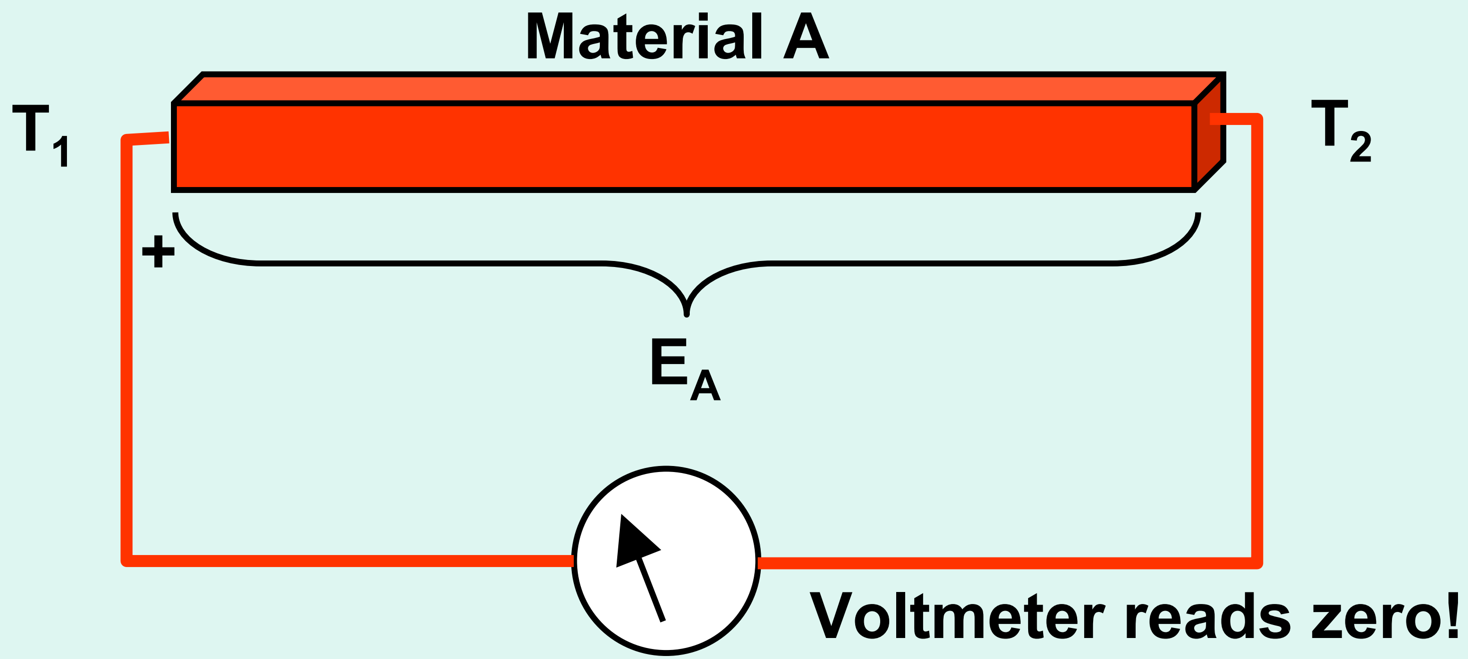
Thermocouple



$$E_A = \alpha_A(T_1 - T_2)$$

α = Seebeck Coefficient

Thermocouple



$$E_A = \alpha_A(T_1 - T_2)$$

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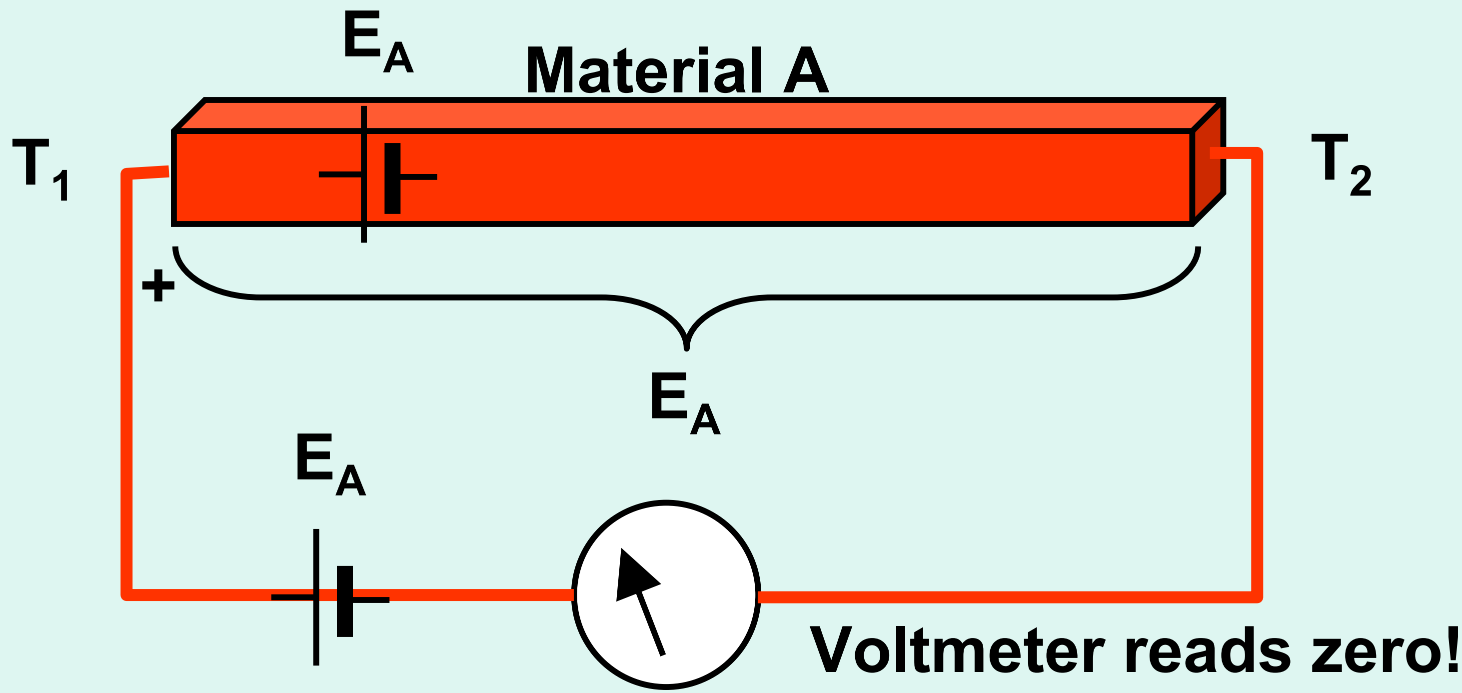
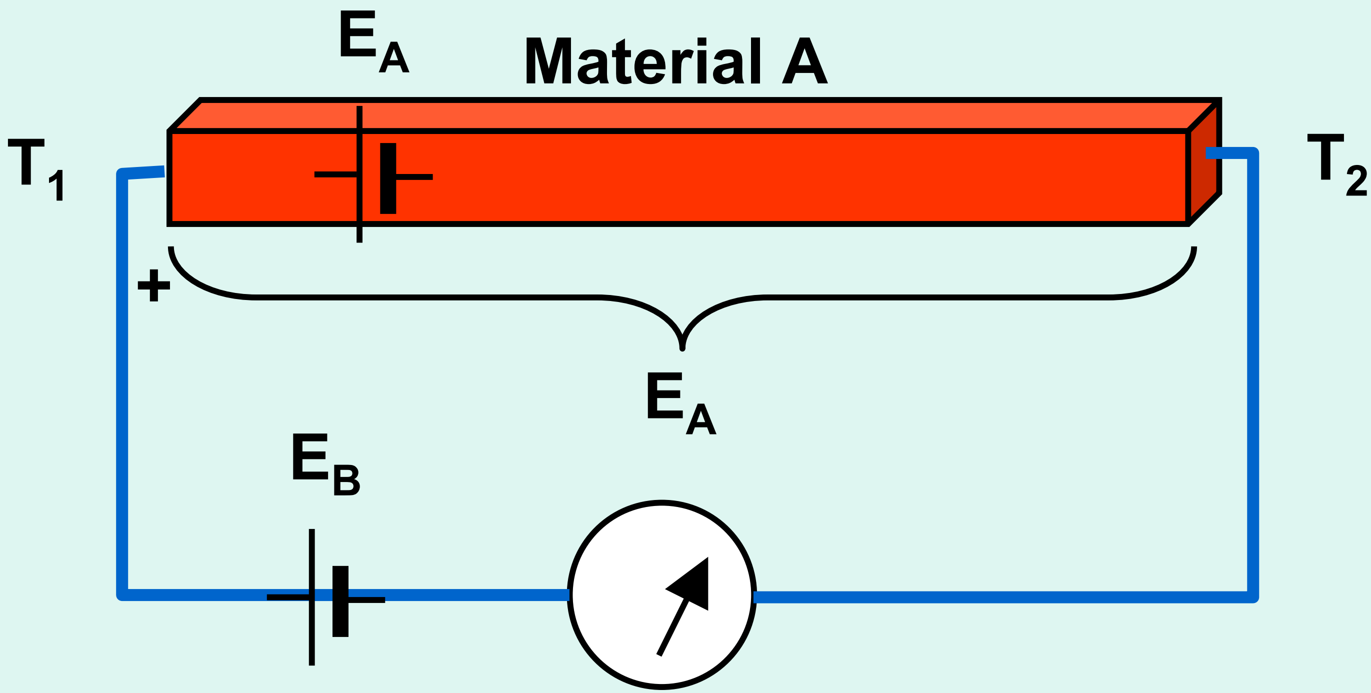
Thermocouple



$$E_A = \alpha_A(T_1 - T_2)$$

α = Seebeck Coefficient

Thermocouple

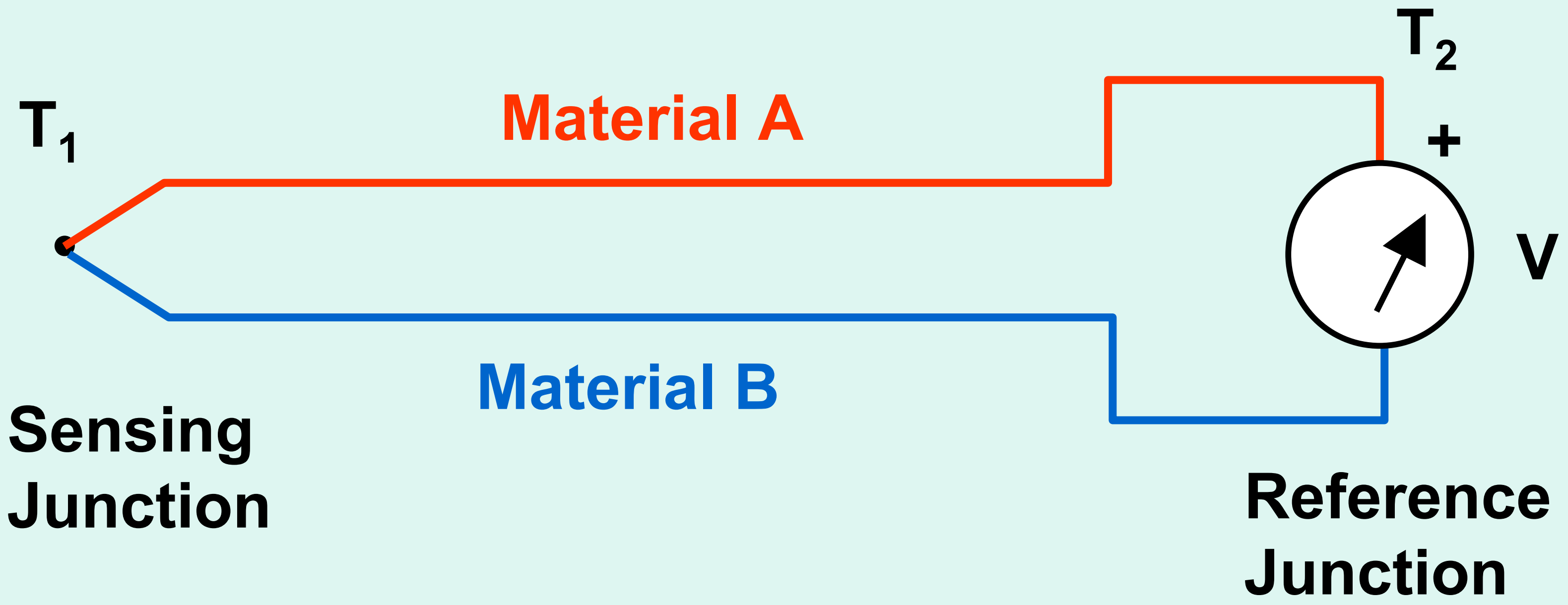


$$E_A - E_B = \alpha_A(T_1 - T_2) - \alpha_B(T_1 - T_2) = (\alpha_A - \alpha_B)(T_1 - T_2)$$

α = Seebeck Coefficient

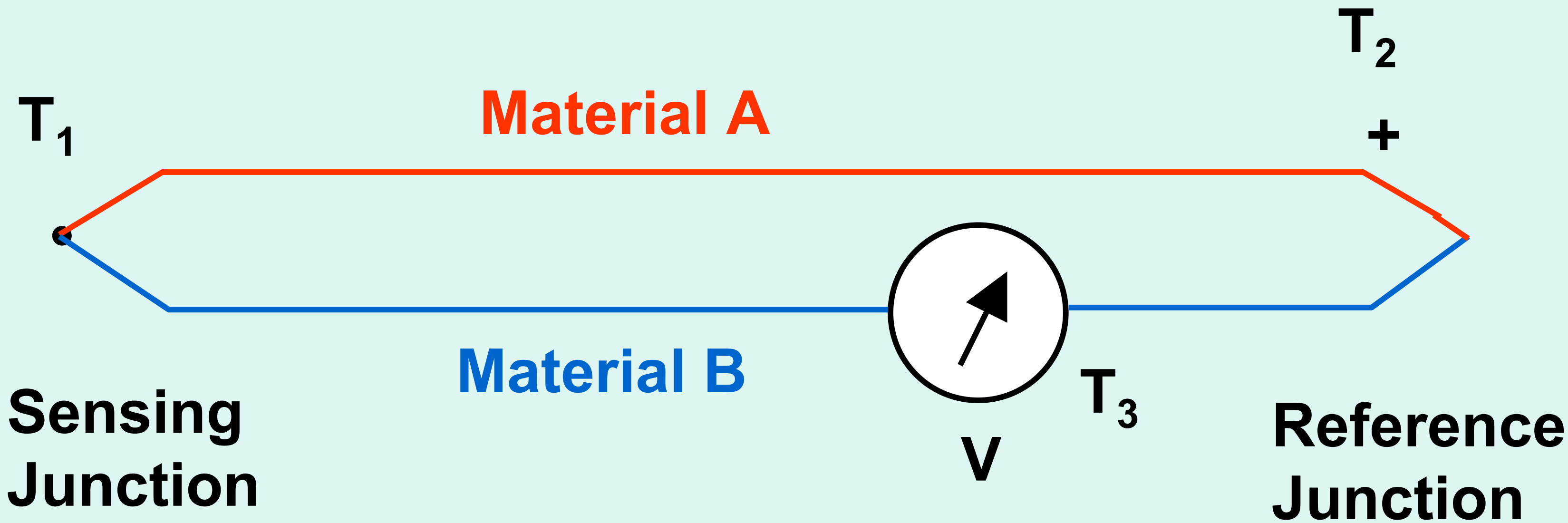
$\alpha_{AB} = \alpha_A - \alpha_B$ = Seebeck Coefficient for Materials A & B

Thermocouple



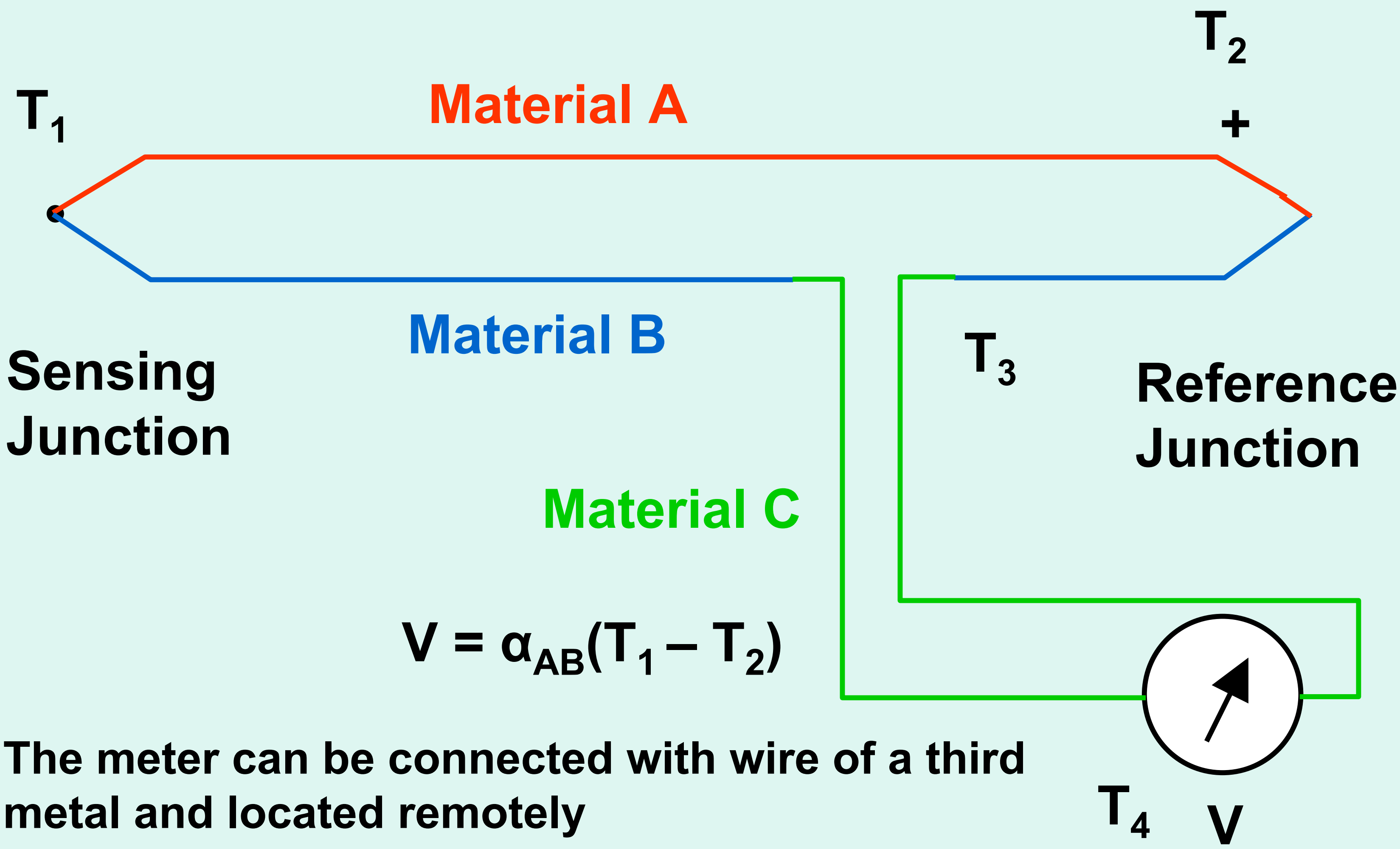
$$V = \alpha_{AB}(T_1 - T_2)$$

Thermocouple



$$V = \alpha_{AB}(T_1 - T_2)$$

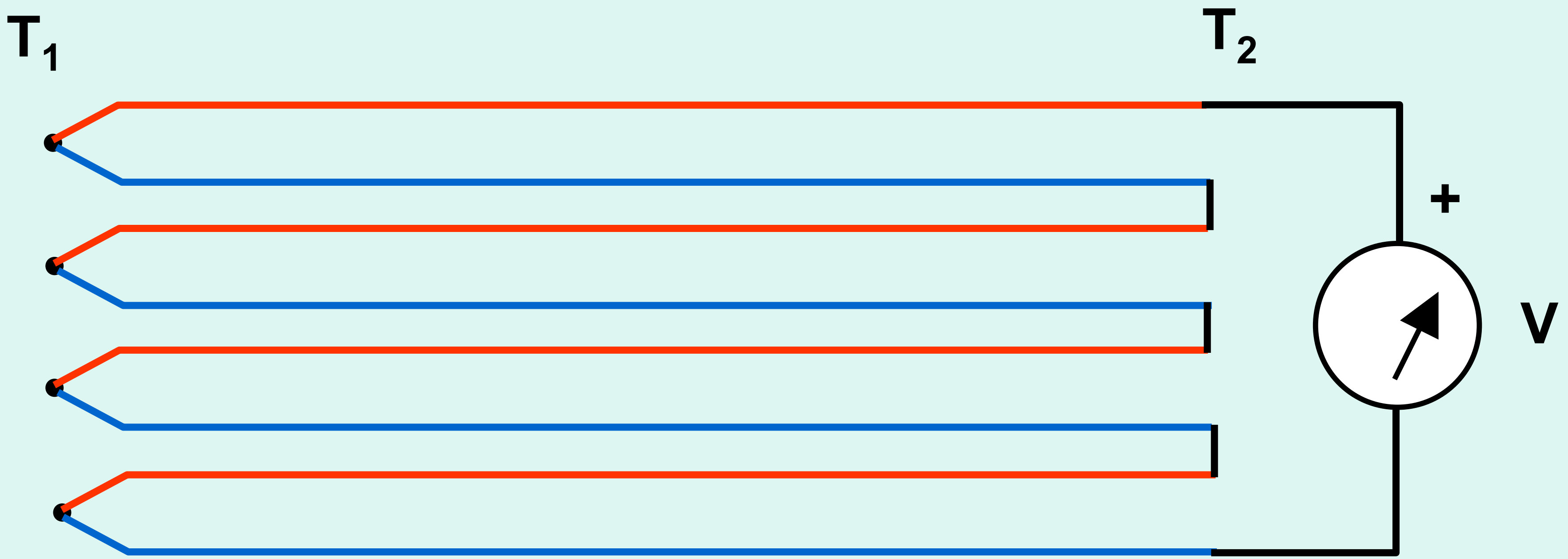
Thermocouple



$$V = \alpha_{AB}(T_1 - T_2)$$

The meter can be connected with wire of a third metal and located remotely

Thermopile

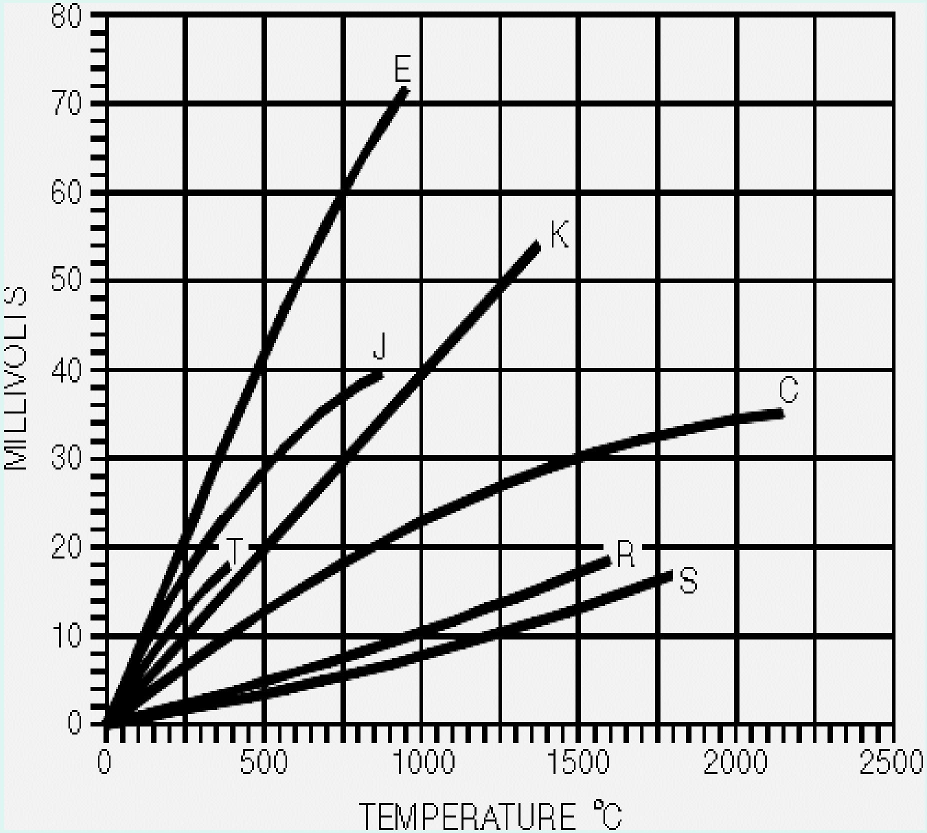


$$V = N\alpha_{AB}(T_1 - T_2)$$

Where N is the number of thermocouples

Thermocouple

ANSI Type	Materials	Temp. Range	Voltage (mV)
T	Copper Constantan	-200 to 350°C	-5.60 to 17.82
J	Iron Constantan	0 to 750°C	0 to 42.28
E	Chromel Constantan	-200 to 900°C	-8.82 to 68.78
K	Chromel Alumel	-200 to 1250°C	-5.97 to 50.63
R	Platinum-13% Rhodium Platinum	0 to 1450°C	0 to 16.74



$$V = \alpha(T - T_0) + \beta(T - T_0)^2$$

Thermocouple Table for Type K (Chromel – Alumel) Thermocouples

Thermoelectric Voltage in mV

°C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	1.203
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	1.612
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	2.023
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	2.436
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	2.851
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	3.267
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	3.682
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	4.096

Sample Problem

A type K thermocouple is to be used to measure the temperature of an infant incubator in the Neonatal Intensive Care Unit (NICU). This incubator should be at a temperature of 35 °C, and the NICU itself is kept at a temperature of 23 °C.

1. If the incubator is indeed at 35 °C, what will the thermocouple voltage be?

2. If the reference junction of the thermocouple is placed in an ice bath, what will the thermocouple voltage be?

Work the second part of the problem first:

The reference junction is at 0 °C and the sensing junction is at 35 °C, so the voltage can be found from the table

V = 1.407 mV

Thermocouple Table for Type K (Chromel – Alumel) Thermocouples

Thermoelectric Voltage in mV

°C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	1.203
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	1.612
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	2.023
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	2.436
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	2.851
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	3.267
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	3.682
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	4.096

Now determine the voltage for a thermocouple with its reference junction at 0 °C and its sensing junction at room temperature, 23 °C.

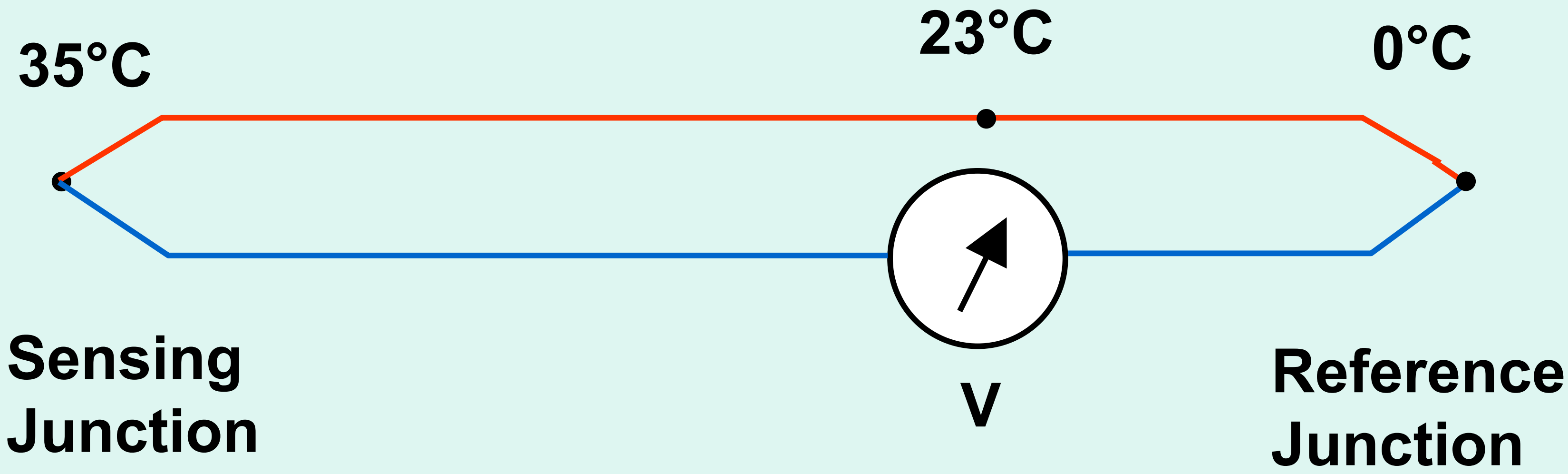
V = 0.919 mV

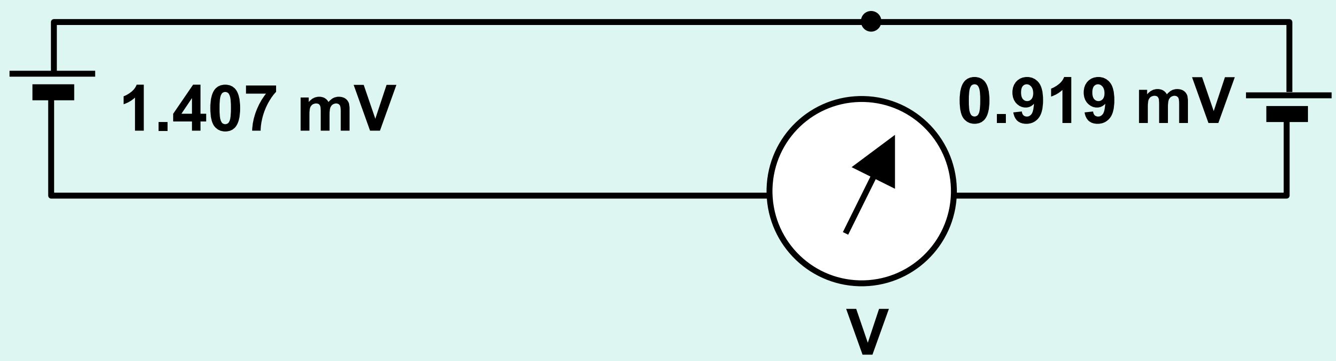
Thermocouple Table for Type K (Chromel – Alumel) Thermocouples

Thermoelectric Voltage in mV

°C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	1.203
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	1.612
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	2.023
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	2.436
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	2.851
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	3.267
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	3.682
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	4.096

Equivalent Circuit



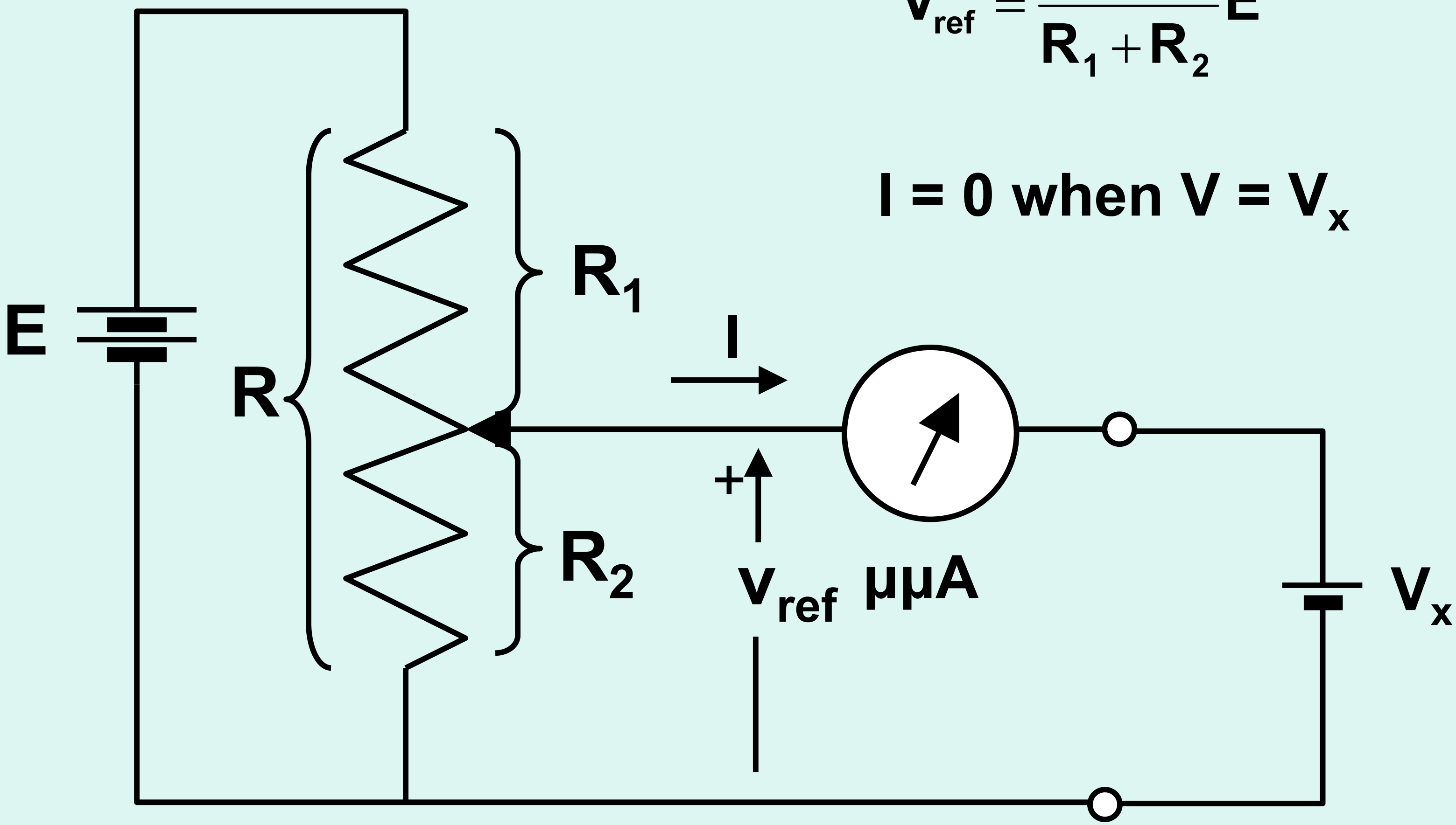


$$V = 1.407 - 0.919 = 0.488 \text{ mV}$$

Potentiometer

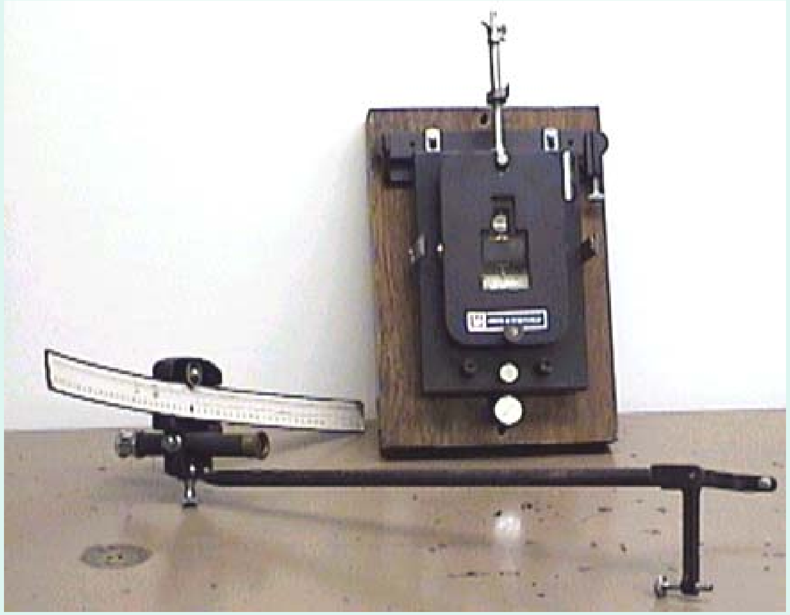
$$V_{ref} = \frac{R_2}{R_1 + R_2} E$$

I = 0 when V = V_x



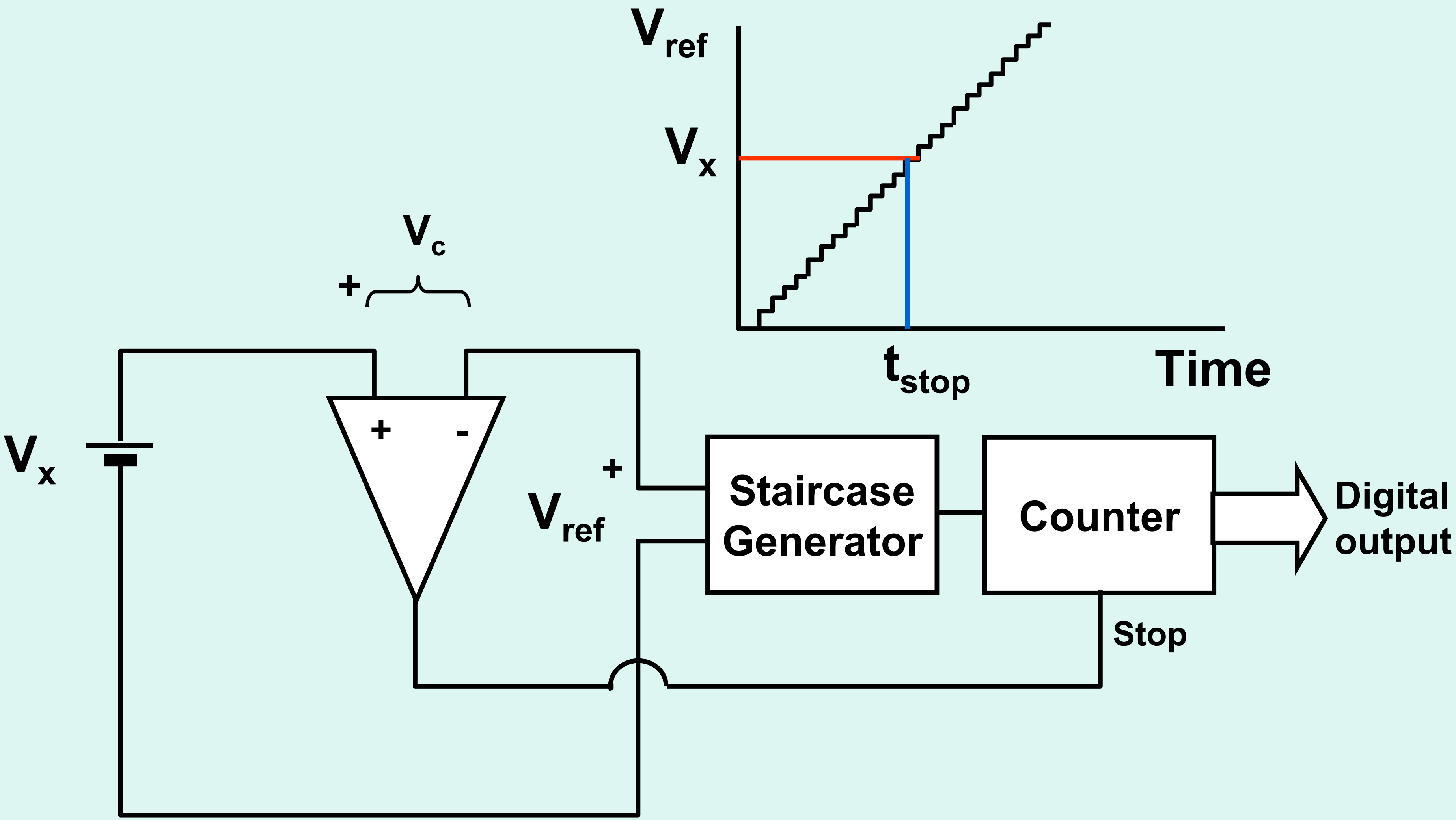
Historical Potentiometer

Leeds and Northrup
K-2 Potentiometer



Galvanometer

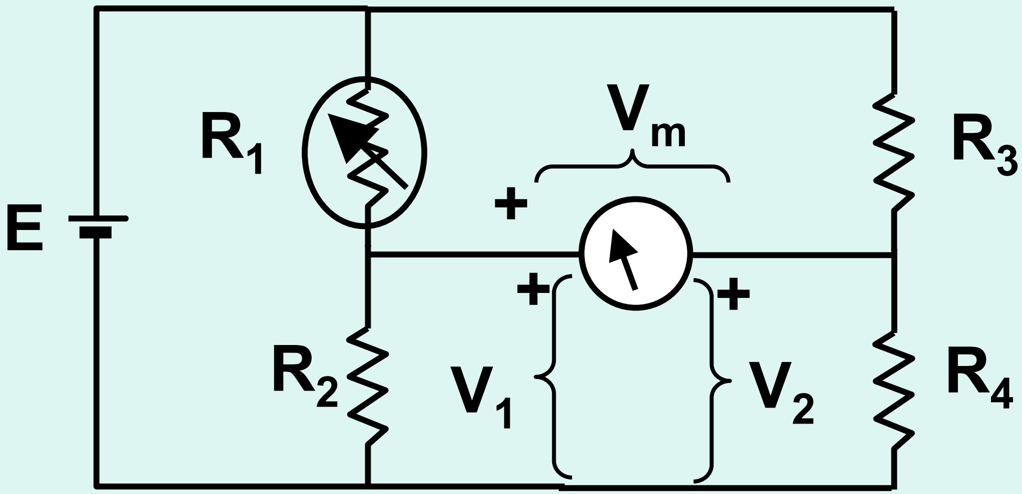
Modern Potentiometers: Analog to Digital Converters



Application: Electronic Thermometer

- Easy to read digital display
- Rapid response
- Equilibrium indication
- Disposable protective sheath
- Inexpensive enough for home use

Wheatstone Bridge



$$V_1 = \frac{R_2}{R_1 + R_2} E$$

$$V_2 = \frac{R_4}{R_3 + R_4} E$$

Meter voltage

$$V_m = V_1 - V_2$$

$$\mathbf{V_m} = \frac{R_2}{R_1 + R_2} E - \frac{R_4}{R_3 + R_4} E$$