
Temperature

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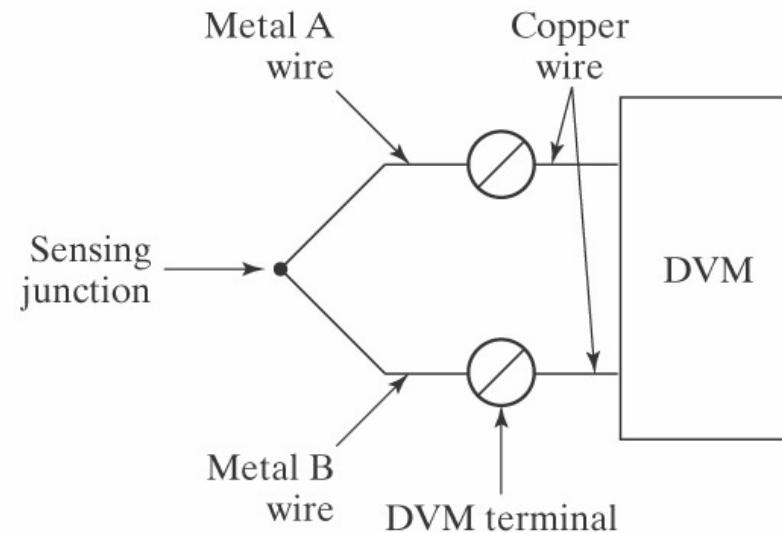
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Temperature Measurement Principles and Devices

- ❑ Thermoelectric (Seebeck) effect
- ❑ Temperature-dependent resistance
- ❑ Mechanical mismatch of thermal expansion
- ❑ Fluid volume expansion and/or pressure change
- ❑ Temperature-dependent semiconductor band gap
- ❑ Thermal radiation
- ❑ Material phase change
- ❑ Conventional “thermometer”
- ❑ Thermocouple
- ❑ Pyrometer
- ❑ Thermistor
- ❑ Bimetallic strip
- ❑ Resistance temperature detector (RTD)
- ❑ Infrared thermometer

Thermocouples

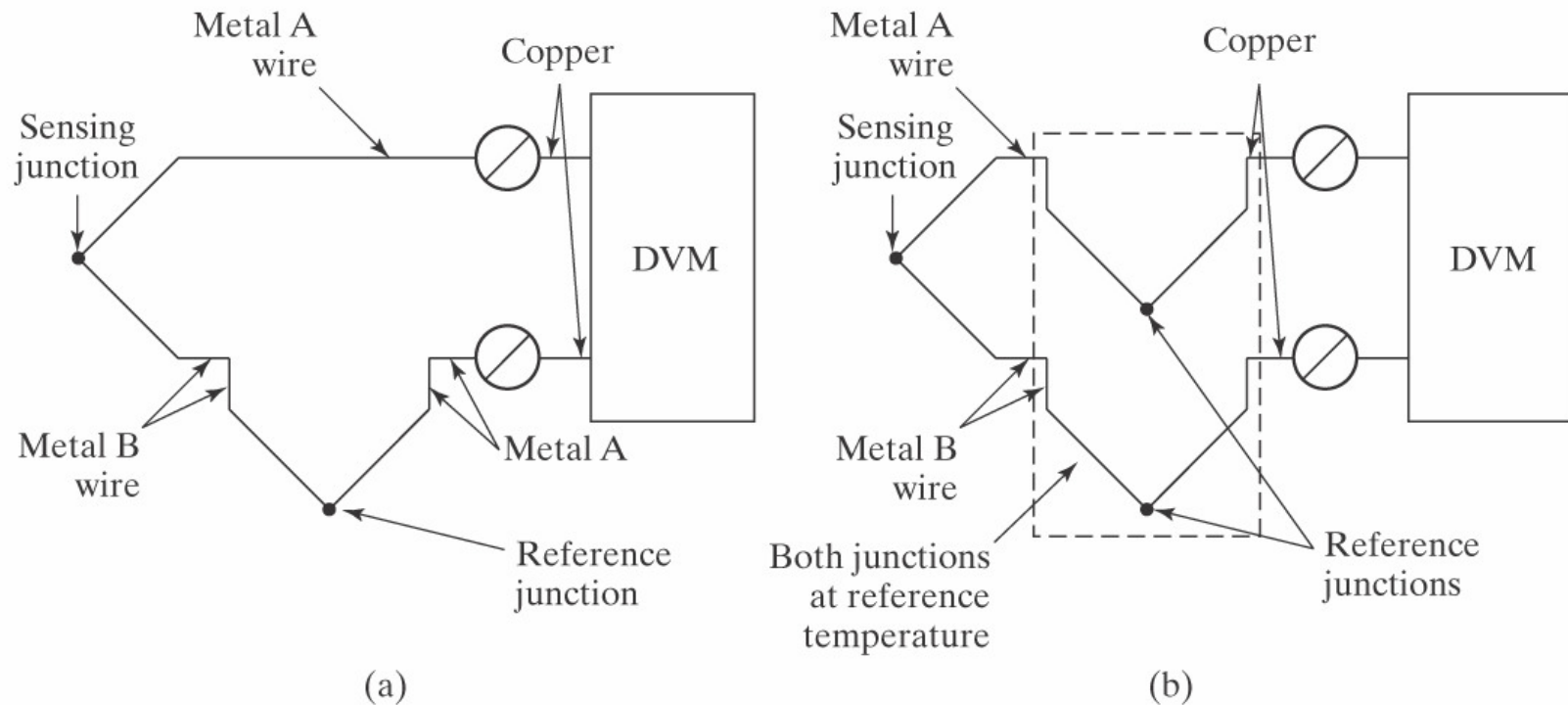
- ❑ Electromotive force (emf) is produced at the open ends of two dissimilar metallic wires as temperature changes.
- ❑ Voltage V is proportional to change in temperature T .
- ❑ Thermocouples are inexpensive, have a wide temperature range, and do not require external power.
- ❑ However, voltage change is generally very small and a second, independent sensor is typically required for junction compensation.



$$\Delta V = \beta \Delta T$$

β = Seebeck coefficient ($\mu\text{V}/^\circ\text{C}$)

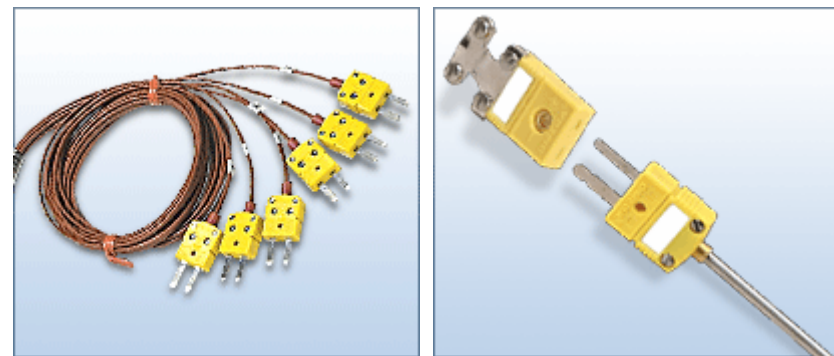
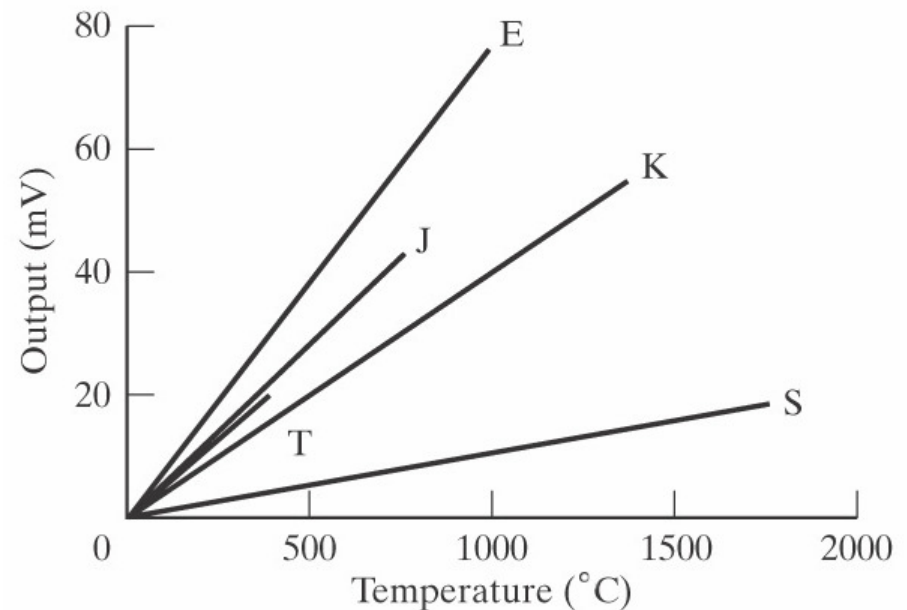
Thermocouple Reference Junction



- ❑ A reference junction (held in 0 °C ice, for example) is needed to overcome the “junctions” associated with wire contacts and measurement.
- ❑ In practice it is convenient to use an equivalent configuration (shown above right), with a separate, independent sensor to measure the temperature of the reference junctions.

Thermocouple Selection Criteria

- ❑ Operating range
- ❑ Sensitivity ($\text{mV}/^\circ\text{C}$)
- ❑ Accuracy
- ❑ Linearity
- ❑ Form factor
- ❑ Response time
- ❑ Environmental robustness
- ❑ Cost



Image(s) from <http://www.omega.com/temperature/>, retrieved September 2008

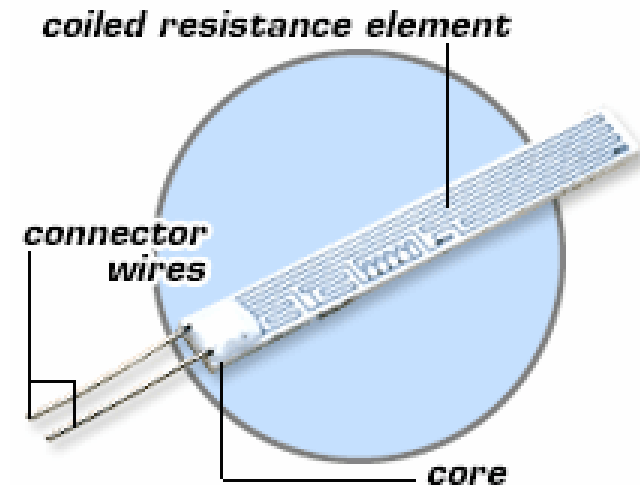
Resistance Temperature Detector (RTD)

- ❑ Based on the principle that resistance changes with temperature, and can be quantified with coefficient-weighted equations such as:

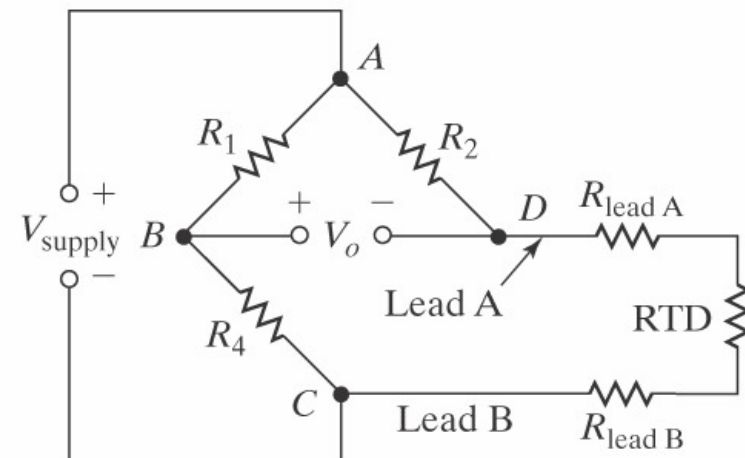
$$R_T = R_0 \{ 1 + \alpha [T - \delta(0.01T - 1)(0.01T) - \beta(0.01T - 1)(0.01T)^3] \}$$

- ❑ Fabricated as metal film or wire coil, with platinum as most common material.
- ❑ Among the most accurate and stable of temperature sensing options (e.g. 0.1% at 100 °C).
- ❑ Various bridge circuits can improve sensitivity and also reduce uncertainty from lead wire resistance.
- ❑ Relatively expensive and slow.

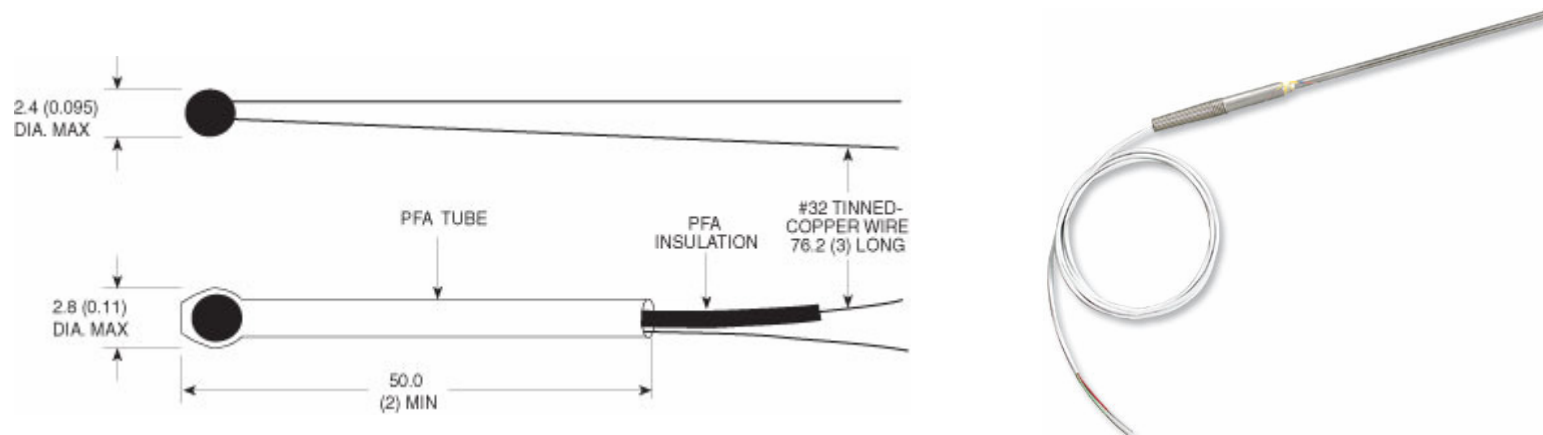
Typical RTD Design



Image(s) from <http://www.omega.com/temperature/>
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Thermistors



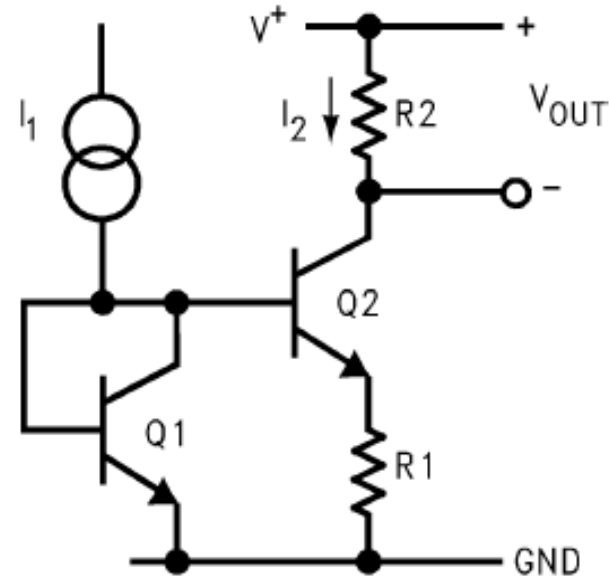
- ❑ Based on the principle that resistance changes with temperature, but made of semiconducting metal oxides rather than metal.
- ❑ Extremely nonlinear relationship between resistance and temperature, such as:

$$\frac{1}{T} = A + B \ln R + C (\ln R)^3$$

- ❑ Small, fast, accurate, and relatively insensitive to parasitic resistance in lead wires.
- ❑ Disadvantages of nonlinearity, fragility, and relatively low temperature range.

Integrated-Circuit Temperature Sensors


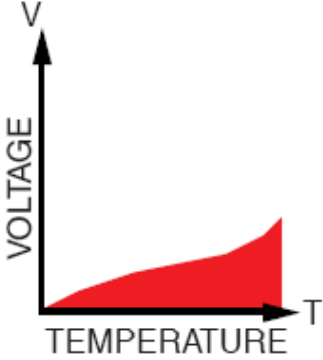

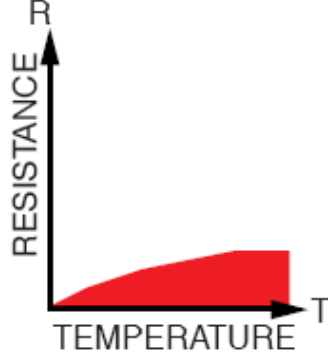

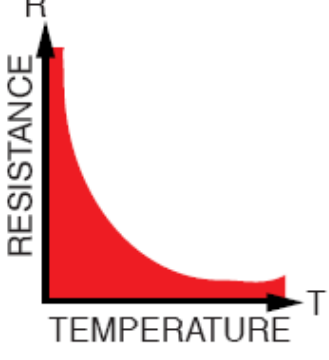

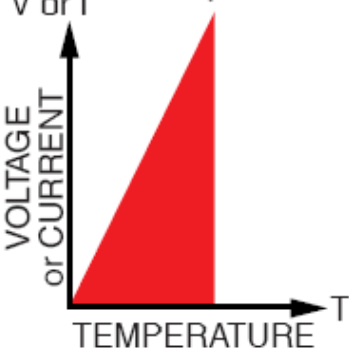
- ❑ The base-emitter voltage (V_{BE}) of a silicon NPN transistor is temperature-dependent.
- ❑ Various arrangements of transistors and diodes can provide a linear relationship between voltage and temperature (e.g. $10 \text{ mV}/^\circ\text{C}$).
- ❑ Relatively accurate to $\sim 0.5 \text{ }^\circ\text{C}$.
- ❑ Temperature range limited, typically $-50 \text{ }^\circ\text{C}$ to $150 \text{ }^\circ\text{C}$.
- ❑ Easy to integrate with other electronic devices, higher levels of integration even provide digital output.



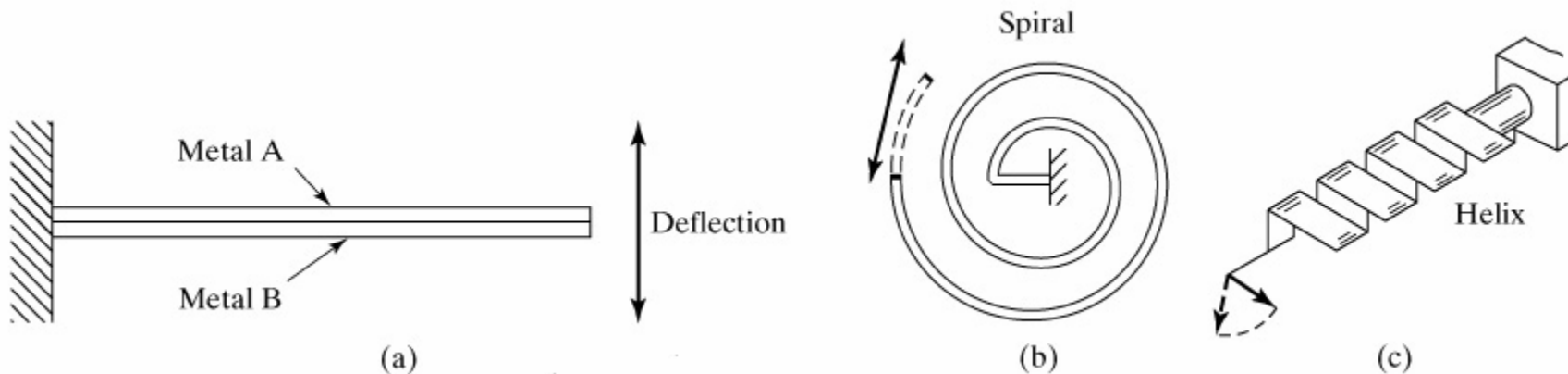
$$V_{BE1} - V_{BE2} = \frac{kT}{q} \ln \frac{J_{E1}}{J_{E2}}$$

k = Boltzman constant
 q = charge on an electron
 J = current density

Relative Advantages & Disadvantages

| | Thermocouple   | RTD   | Thermistor   | I. C. Sensor   |
|----------------------|---|--|--|---|
| Advantages | <input type="checkbox"/> Self-powered <input type="checkbox"/> Simple <input type="checkbox"/> Rugged <input type="checkbox"/> Inexpensive <input type="checkbox"/> Wide variety <input type="checkbox"/> Wide temperature range | <input type="checkbox"/> Most stable <input type="checkbox"/> Most accurate <input type="checkbox"/> More linear than thermocouple | <input type="checkbox"/> High output <input type="checkbox"/> Fast <input type="checkbox"/> Two-wire ohms measurement | <input type="checkbox"/> Most linear <input type="checkbox"/> Highest output <input type="checkbox"/> Inexpensive |
| Disadvantages | <input type="checkbox"/> Non-linear <input type="checkbox"/> Low voltage <input type="checkbox"/> Reference required <input type="checkbox"/> Least stable <input type="checkbox"/> Least sensitive | <input type="checkbox"/> Expensive <input type="checkbox"/> Current source required <input type="checkbox"/> Small ΔR <input type="checkbox"/> Low absolute resistance <input type="checkbox"/> Self-heating | <input type="checkbox"/> Non-linear <input type="checkbox"/> Limited temperature range <input type="checkbox"/> Fragile <input type="checkbox"/> Current source required <input type="checkbox"/> Self-heating | <input type="checkbox"/> $T < 200^{\circ}\text{C}$ <input type="checkbox"/> Power supply required <input type="checkbox"/> Slow <input type="checkbox"/> Self-heating <input type="checkbox"/> Limited configurations |

Bimetallic Strips

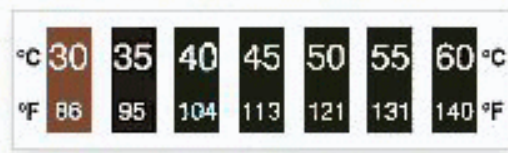
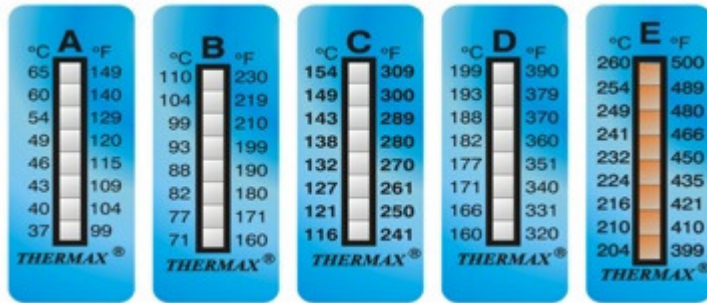


- ❑ Materials with different thermal expansion coefficients α expand at different rates.

$$\Delta L_A = \alpha_A L_0 \Delta T \quad \Delta L_B = \alpha_B L_0 \Delta T$$

- ❑ A bonded bimetallic strip bends or otherwise deforms when heated or cooled.
- ❑ Applications are often limited to coarse measurements, although fiber optics and other methods can be used to detect small deflections with higher resolution.

Phase-Changing Temperature Indicators



- ❑ Color changes above a threshold temperature.
- ❑ Both reversible and irreversible options.
- ❑ Applications generally limited to coarse measurements and inspection.

Pyrometers and Infrared Thermometers

- ❑ Pyrometers make non-contact temperature measurement based on thermally-generated radiation.
- ❑ Pyrometers can measure extreme temperatures up to 4000 °C.
- ❑ Effective for materials with high emissivity ϵ .
- ❑ Infrared thermometers also measure radiation, generally for lower temperatures.

