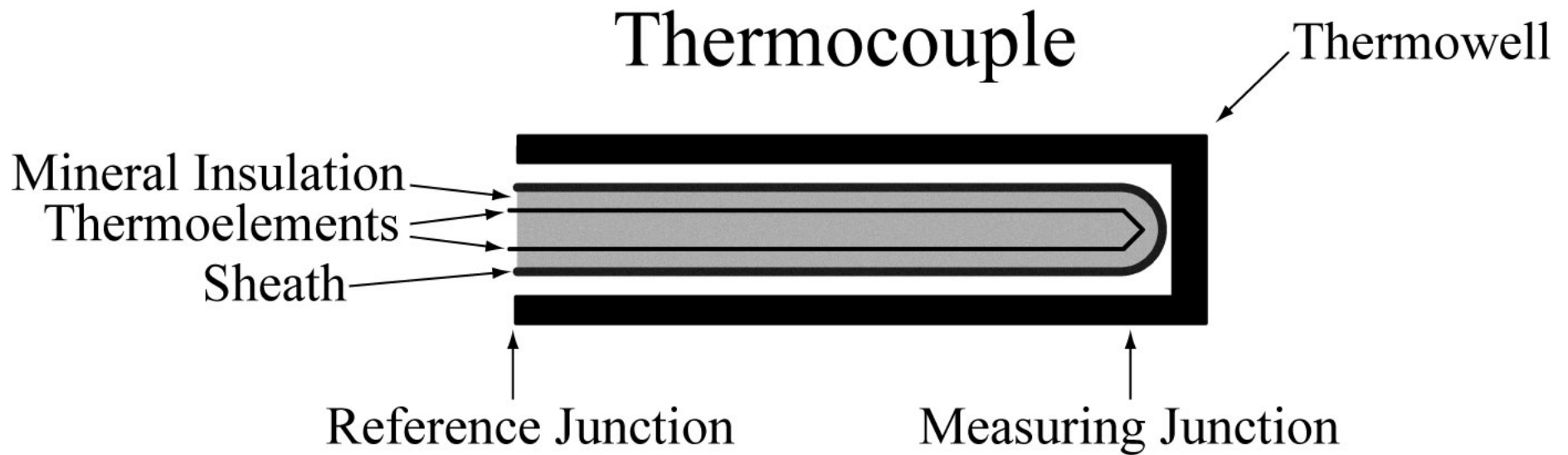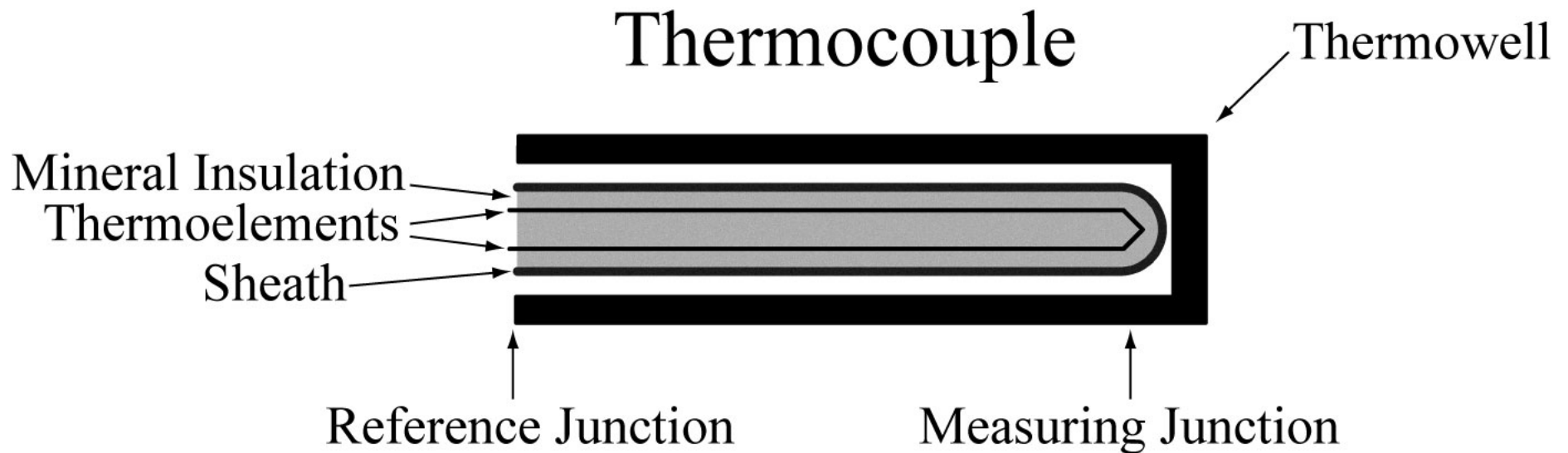# Thermocouple

The two thermoelements of a thermocouple are two different metals. When a thermoelement is in a thermal gradient a voltage is developed between the ends. This phenomenon is called the "Seebeck" effect. The two thermoelements have different Seebeck coefficients, typically one positive and one negative. So when the thermocouple is in a thermal gradient a voltage is developed at the reference junction between the two thermoelements. With calibration, this voltage indicates the difference between the temperature of the measuring junction and the temperature of the reference junction.

Thermocouple

Thermowell

Mineral Insulation
Thermoelements
Sheath

Reference Junction

Measuring Junction

In normal operation the reference junction is held at a constant known temperature so the temperature at the measuring junction can be determined by the voltage between the thermoelements. A very common type of thermocouple is called the "Type K" thermocouple. Its thermoelements are two metal alloys "Chromel" and "Alumel". Its calibration is approximately 40 μV/°C. The thermowell is a physical structure to protect the thermocouple from damage.

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One problem in practical real application of thermocouples is that the thermowell slows down the temperature measurement because some significant time is required for the temperature of the measuring junction to respond to a sudden change in temperature outside the thermowell. This lagging response has been analyzed and it is approximately a first order system type lag. That is, the response to a step change in temperature ΔT_{tw} outside the thermowell is of the form

$$\Delta T_{tc}(t) = \Delta T_{tw}\left(1 - e^{-t/\tau}\right)u(t)$$

The transfer function from thermowell exterior temperature to measuring junction temperature is $H(s) = \dfrac{1}{\tau} \dfrac{1}{s + 1/\tau}$. Let the thermocouple signal be sampled at 1 kHz and let the time constant be 200 ms. Design a digital compensator to speed up the temperature measurement.

The impulse response of the thermocouple/thermowell system is

$h(t) = \dfrac{e^{-t/\tau}}{\tau} u(t) = 5e^{-5t} u(t)$. If we sample that at 1 kHz the equivalent

discrete-time impulse response is $h[n] = \left[5e^{-5t} u(t) \right]_{t \to nT_s}$ or

$h[n] = 5e^{-0.005n} u[n]$. The discrete-time transfer function is then

$H(z) = \dfrac{5z}{z - e^{-0.005}} = \dfrac{5z}{z - 0.995}$.

The equivalent discrete-time transfer function is

$$H(z) = \frac{5z}{z - e^{-0.005}} = \frac{5z}{z - 0.995}.$$

The ideal discrete-time transfer function would have no poles or zeros making the system respond instantly. So the digital compensator must have a transfer function of

$$H_c(z) = \frac{z - 0.995}{5z} = 0.2\left(1 - 0.995z^{-1}\right)$$

making the overall system transfer function $H_{ideal}(z) = 1$. The impulse response of the compensator is then

$$h_c[n] = 0.2\left(\delta[n] - 0.995\delta[n-1]\right)$$

The compensator can be realized with this discrete-time system.