Today, we will:

- Review the pdf module: **Temperature Measurement**
- Do some example problems – temperature measurement

Example: Thermocouples

Given: A type S thermocouple is placed into an oven to measure the temperature. An ice bath is used as a reference junction in the normal fashion. The output voltage is 4.005 mV.

(*a*) To do: Calculate the temperature of the oven.

(*b*) To do: If ambient air ($T_{ambient}$ = 20°C) were used as the reference junction instead of the ice bath, what voltage would the thermocouple instrument read?

Solution:

(a) From the brief table, for type S thermocouple, @ $V = 4.005$ mV, interpolate → $T = 476.7\,^\circ C$

[With a proper ice bath at 0°C, this voltage is V_{1-R}]

(b) • Let ① = actual temperature → $T_1 = 476.7\,^\circ C$, $V_{1-R} = 4.005$ mV

[this voltage is relative to 0°C by definition]

• Let ② = ambient temperature → $T_2 = 20.0\,^\circ C$ → $V_{2-R} = 0.113$ mV (from table)

(our non-standard reference temp.)

• Now use our standard notation equation:

$$V_{1-2} = V_{1-R} - V_{2-R} = 4.005 - 0.113 = 3.892 \text{ mV} = V_{1-2}$$

[This is the voltage we would read if the reference junction were 20°C instead of 0°C (ice bath).]

NOTE: You cannot solve this problem properly by adding temperatures (although many students are tempted to add temperatures)

E.g. $T_{apparent} = 476.7 - 20 = 456.7\,^\circ C$ → look up in table (interpolate)

WRONG! → ~~$V_{apparent} = 3.809$ mV~~

(answer is close, but is not correct)

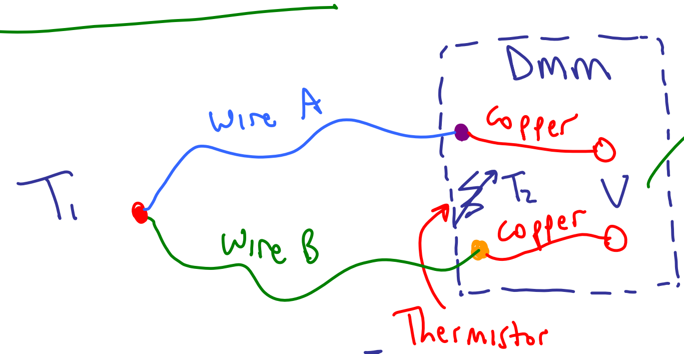
★ You cannot add temperatures! Always add voltages

Q: HOW DO DMMs MEASURE T W/O AN ICE BATH?

A: They use **Electronic Cold Junction Compensation** ✩

(no ice bath required)

How does it work?



measure this voltage & adjust it to compensate for the lack of an ice bath reference @ T = 0°C

- Use a thermistor to measure T_2 at the two junctions where the thermocouple wires connect to the DMM
- Once we know T_2, we can compensate for the lack of an ice bath (as in the previous example problem)

Essentially, we replace the ice bath (0°C) with a different reference temperature, T_2 & measure this T_2 internally in the DMM

- How to correct for $T_2 \neq 0°C$?

(1) Software compensation: Use $V_{1-R} = V_{1-2} + V_{2-R}$ as in previous example

"look this up" in a table & interpolate (V_{2-R})

OR, use a polynomial curve fit to get V_{2-R}

(2) Hardware compensation: Add a voltage to make $V = V_{1-R}$ using the measured T_2

(We add a "fake" voltage to pretend we have an ice bath)

[In either case, calculate T_1 for the value of V_{1-R}]

(Then display T_1 on the DMM display)

Example: Thermocouples

Given: A type K thermocouple is used to measure the temperature in a freezer compartment. The reference junction is connected properly to an ice bath, and the voltage output from the thermocouple circuit is –2.721 mV.

To do: Calculate the temperature in the freezer compartment. *Give your answer in units of ^{o}C to three significant digits*. *Note*: Use the "brief" thermocouple tables for consistency (provided below for convenience).

Thermocouple Voltage Data – Table 9.2 of Wheeler, A. J. and Ganji, A. R., *Introduction to Engineering Experimentation*, Ed. 2, Pearson Education Inc. (Prentice Hall), Upper Saddle River, NJ, 2004.

TABLE 9.2 Millivolt Output of Common Thermocouples (Reference Junction at 0°C)

Temperature (°C)	Thermocouple type					
	T	E	J	K	R	S
−250	−6.181	−9.719		−6.404		
−200	−5.603	−8.824	−7.890	−5.891		
−150	−4.648	−7.279	−6.499	−4.912		
−100	−3.378	−5.237	−4.632	−3.553		
−50	−1.819	−2.787	−2.431	−1.889		
0	0.000	0.000	0.000	0.000	0.000	0.000
20	0.789	1.192	1.019	0.798	0.111	0.113
40	1.611	2.419	2.058	1.611	0.232	0.235
60	2.467	3.683	3.115	2.436	0.363	0.365
80	3.357	4.983	4.186	3.266	0.501	0.502
100	4.277	6.317	5.268	4.095	0.647	0.645
120	5.227	7.683	6.359	4.919	0.800	0.795
140	6.204	9.078	7.457	5.733	0.959	0.950
160	7.207	10.501	8.560	6.539	1.124	1.109
180	8.235	11.949	9.667	7.338	1.294	1.273

Solution:

Interpolate:

T (°C)	V (mV)
−100	−3.553
−75.0 ←	−2.721
−50	−1.889

Answer to 3 digits: $T = -75.0^{\circ}C$

Example: Thermocouples

Given: A type K thermocouple is used to measure three temperatures: T_1 = 60.0°C, T_2 = -50.0°C, and T_3 = 180.0°C. The thermocouple voltages are measured properly with an ice bath reference at 0.00°C.

(*a*) To do: Determine the voltage readings $V_{1\text{-R}}$, $V_{2\text{-R}}$, and $V_{3\text{-R}}$, for the three temperatures.

(*b*) To do: Using the voltages of Part (a), verify the law of intermediate temperatures.

Solution:

(a) See the brief thermocouple table for a type K thermocouple

@ $T_1 = 60.0°C \rightarrow V_{1\text{-}R} = 2.436$ mV

@ $T_2 = -50.0°C \rightarrow V_{2\text{-}R} = -1.889$ mV

@ $T_3 = 180°C \rightarrow V_{3\text{-}R} = 7.338$ mV

(b) Law of Intermediate Temperatures:

$$V_{1\text{-}3} = V_{1\text{-}2} + V_{2\text{-}3}$$

$$V_{1\text{-}R} - V_{3\text{-}R} = V_{1\text{-}R} - V_{2\text{-}R} + V_{2\text{-}R} - V_{3\text{-}R}$$

#'s:

$$2.436 - 7.338 = 2.436 - (-1.889) + (-1.889) - 7.338 \text{ mV}$$

$$-4.902 \text{ mV} = -4.902 \text{ mV} \quad \checkmark \text{verified}$$

You can see that the law of intermediate temperatures must hold regardless of the 3 temperatures (⊕ or ⊖, does not matter)

i.e.,

$$V_{1\text{-}R} - V_{3\text{-}R} = V_{1\text{-}R} - V_{2\text{-}R} + V_{2\text{-}R} - V_{3\text{-}R}$$

$$0 = 0 \quad \checkmark(\text{verified})$$