Thermocouple: what if the reference temperature is not $0\,^\circ\mathrm{C}$?

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As explained in the lecture, in Appendix B of the book the values of $\mathrm{E}_{\mathrm{AB}}(T_2 \to T_1)$ for the case $T_1 = 0\,^\circ\mathrm{C}$ are tabulated. But what shall we do when $T_1 \neq 0\,^\circ\mathrm{C}$?

In the book, it is suggested to use a linear approximation for $\mathrm{E}_{\mathrm{AB}}(T_2 \to T_1)$, which—as we shall see—may introduce significant errors. Specifically, the book suggests to use that

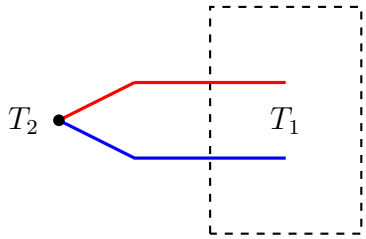
$$\mathrm{E}_{\mathrm{AB}}(T_2 \to T_1) \approx \mathrm{E}_{\mathrm{AB}}(T_2 - T_1 \to 0\,^\circ\mathrm{C}) \tag{1}$$

I marked this approximation in red because **it must not be used in this course**. The method we will use is instead exact and consists of the following steps. Note that

$$\begin{aligned}
\mathrm{E}_{\mathrm{AB}}(T_2 \to T_1) &= \mathrm{E}_{\mathrm{A}}(T_2 \to T_1) - \mathrm{E}_{\mathrm{B}}(T_2 \to T_1) && (2)\\
&= \mathrm{E}_{\mathrm{A}}(T_2 \to 0\,^\circ\mathrm{C}) + \mathrm{E}_{\mathrm{A}}(0\,^\circ\mathrm{C} \to T_1) - \mathrm{E}_{\mathrm{B}}(T_2 \to 0\,^\circ\mathrm{C}) - \mathrm{E}_{\mathrm{B}}(0\,^\circ\mathrm{C} \to T_1) && (3)\\
&= \mathrm{E}_{\mathrm{AB}}(T_2 \to 0\,^\circ\mathrm{C}) - \mathrm{E}_{\mathrm{AB}}(T_1 \to 0\,^\circ\mathrm{C}). && (4)
\end{aligned}$$

Note now that both $\mathrm{E}_{\mathrm{AB}}(T_2 \to 0\,^\circ\mathrm{C})$ and $\mathrm{E}_{\mathrm{AB}}(T_1 \to 0\,^\circ\mathrm{C})$ can be found in the table in Appendix B. Hence, we can compute $\mathrm{E}_{\mathrm{AB}}(T_2 \to T_1)$ exactly.

Example: Consider the thermocouple in the figure and assume that the reference junction is at $T_1 = 25\,^\circ\mathrm{C}$ and that the tension at the output of the thermocouple is $U = -1.51\,\mathrm{mV}$. We use the



formula we have just derived:

$$U = \mathrm{E}_{\mathrm{AB}}(T_2 \to T_1) = \mathrm{E}_{\mathrm{AB}}(T_2 \to 0\,^\circ\mathrm{C}) - \mathrm{E}_{\mathrm{AB}}(T_1 \to 0\,^\circ\mathrm{C}). \tag{5}$$

Furthermore, we read from the table that $\mathrm{E_{AB}}(T_1 \to 0\,^\circ\mathrm{C}) = 0.992\,\mathrm{mV}$ when $T_1 = 25\,^\circ\mathrm{C}$. Hence,

$$\mathrm{E_{AB}}(T_2 \to 0\,^\circ\mathrm{C}) = U + \mathrm{E_{AB}}(T_1 \to 0\,^\circ\mathrm{C}) \tag{6}$$

$$= -1.51\,\mathrm{mV} + 0.992\,\mathrm{mV} = -0.518\,\mathrm{mV}. \tag{7}$$

Using the table, we discover that $T_2 \approx -14\,^\circ\mathrm{C}$.

Using instead the approximation (1) of the book, we would obtain from the table that $T_2 - T_1 = -41\,^\circ\mathrm{C}$, and, hence, $T_2 = -16\,^\circ\mathrm{C}$.

Corrections to solutions (appendix A of the book): As a consequence of the approximation used in the book, some of the solutions to the book problems reported in Appendix A of the book are erroneous. These are the updated solutions of the problems affected by the incorrect approximation.

Problem	Corrected solution
2.21b	$251\,^\circ\mathrm{C}$
2.22	$5.914\,\mathrm{mV}$
2.25	$267\,^\circ\mathrm{C}$