A Thermocouple Measures Not a Temperature but an Integral Between Two Junctions

— With a constant Seebeck coefficient of **41** μV/℃, **100 − 0** ℃ and **500 − 400** ℃ both give **4.100000** mV — the separator is whether the Seebeck coefficient is constant or varies with temperature — [Paper 774]

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— *From thinking to syncing.* —

Abstract

Thermocouples are used as thermometers. But the voltage at the junction of two metals is not set by one temperature.What difference the voltage measures, and how much the reading changes with the choice of reference, are counted.No new theorem or law is claimed. First, with a constant coefficient, equal temperature differences give equal voltages——100 − 0 ℃ and 500 − 400 ℃ both give 4.100000 mV (Section 2). **Second, with a varying coefficient, equal differences give different voltages——4.000000 mV against 4.800000 mV, 1.200000 times** (Section 2). **Third, voltages still add over intervals——the law of intermediate temperatures holds with difference 0 even with a varying coefficient** (Section 2). **Fourth, and this is the core. Mistaking the reference junction gives an error that depends on the coefficient's form——mistaking 25 ℃ gives 25.000000 with a constant coefficient, and 24.074286 to 17.899160 with a varying one** (Section 3). **Fifth, the error looks smaller at higher measuring temperature——21.912255 at 300 ℃** (Section 3). **Sixth, the separator is whether the Seebeck coefficient is constant or varies with temperature——"the temperature was measured with a thermocouple" does not say what was measured until one states the reference temperature and the coefficient's form** (Section 4). **Keywords**: Seebeck effect, thermocouple, reference junction, Seebeck coefficient, law of intermediate temperatures, instruments that measure differences.

Scope of this paper (scope note): **No new theorem or law is claimed——the Seebeck effect, that the voltage is the temperature integral of the Seebeck coefficient, the law of intermediate temperatures, and the need to know the reference junction temperature are all known (Rowe 1995, Kasap 2006).Coefficients are representative——41 µV/°C and $39 + 0.02T$ µV/°C are for comparison; tables of real thermocouple types and higher-order terms are not used.Circuits are not treated——cold-junction compensation circuits and instrument noise are not treated.Generation is not treated——thermoelectric efficiency and figures of merit are not treated.Homogeneous wires——voltages from inhomogeneity along the wires are not included.Relation to earlier papers**: **Paper 402 showed that the fourth satellite is for the clock, not for the position——there the receiver's clock was unknown, so one more measurement than the position needed was required. Here a thermocouple measures only the integral between junctions, so without separately knowing the reference junction temperature it gives no temperature, and the error from mistaking it depends on the coefficient's form. An unknown reference needs one more hand to pin it down.**What is added is **comparing voltages for equal temperature differences with constant and varying coefficients**, **confirming that the law of intermediate temperatures holds regardless of the coefficient's form**, **deriving reference-junction errors at three temperatures**, and **placing the separator on whether the coefficient is constant**.

1. Notation and the Question

Setting: **the thermocouple voltage is the Seebeck coefficient $S(T)$ integrated from the reference junction temperature T_r to the measured temperature T. For a coefficient linear in temperature it takes the form below.**

$$E(T, T_r) = \int_{T_r}^{T} S(T')\, dT', \qquad S(T) = S_0 + S_1 T, \qquad E(T, T_r) = S_0(T - T_r) + \tfrac{1}{2} S_1 (T^2 - T_r^2)$$

For the constant case take $S = 41$ µV/°C; for the varying case $S_0 = 39$ µV/°C and $S_1 = 0.02$ µV/°C^2.

Question: **does a thermocouple's voltage measure a temperature?**

2. Equal Differences, Different Voltages

Computation 2.1: **voltages for the same 100 °C difference, taken low and high, were derived with both coefficients.**

coefficient	$100 - 0$ °C	$500 - 400$ °C
constant **41** µV/°C	**4.100000** mV	**4.100000** mV
$39 + 0.02T$ µV/°C	**4.000000** mV	**4.800000** mV

Observation 2.2

with a constant coefficient equal differences give equal voltages; with a varying one they differ by 1.200000 times.The voltage is not a temperature difference but the coefficient integrated over the interval——"equal differences, equal voltage" holds only when the coefficient is constant.

Observation 2.3

voltages still add over intervals.0 → 500 ℃ and 0 → 400 ℃ plus 400 → 500 ℃ differed by 0——as an integral it splits over intervals, whatever the coefficient's form.

3. Mistaking the Reference Junction

Computation 3.1: **with the reference junction actually at 25 ℃ but taken as 0 ℃, the voltage was converted to a reading and its error derived.**

measured point	reading (const.)	error (const.)	reading (varying)	error (varying)
100 ℃	75.000000 ℃	25.000000	75.925714 ℃	24.074286
300 ℃	275.000000 ℃	25.000000	278.087745 ℃	21.912255
800 ℃	775.000000 ℃	25.000000	782.100840 ℃	17.899160

Observation 3.2

this is the core: mistaking the reference junction gives an error that depends on the coefficient's form.With a constant coefficient it is exactly 25.000000 everywhere; with a varying one it is 24.074286 at 100 ℃ and 17.899160 at 800 ℃——at high temperature the coefficient is larger, so the same shortfall of voltage converts into a smaller temperature difference.

Observation 3.3

so the error cannot be corrected by a single number.Correcting the 21.912255 at 300 °C with the 24.074286 from 100 °C leaves another error——the only way is to know the reference temperature and correct with the integral of the coefficient.

4. The Separator

Observation 4.1

the separator is whether the Seebeck coefficient is constant or varies with temperature.Constant, the voltage is proportional to the temperature difference and a reference error becomes the same temperature error; varying, equal differences give different voltages and the reference error changes with measuring temperature——"the temperature was measured with a thermocouple" does not say what was measured until one states the reference temperature and the coefficient's form.

Observation 4.2

beside Paper 402.Paper 402 showed that because the receiver clock is unknown, one more satellite than the position needs is required——here, if the reference junction temperature is unknown, the voltage is no temperature. An instrument that measures only differences needs one more hand to pin the reference.

Observation 4.3

what is not said.Real thermocouple tables, compensation circuits and generation efficiency are not treated, and coefficients are representative——what is shown is that a thermocouple measures an integral, and that the reference and the coefficient's form decide the reading.

5. Roll Call and Closing

1. **4.100000 mV constant** (Computation 2.1): **equal differences, equal voltage.**
2. **4.000000 mV varying** (Computation 2.1): **the low side.**
3. **4.800000 mV varying** (Computation 2.1): **the high side.**

4. **1.200000 times** (Observation 2.2): **equal differences differ.**
5. **intermediate difference 0** (Observation 2.3): **intervals add.**
6. **constant error 25.000000** (Computation 3.1): **carried over.**
7. **24.074286 at 100 °C** (Computation 3.1): **varying coefficient.**
8. **21.912255 at 300 °C** (Observation 3.3): **no single correction.**
9. **17.899160 at 800 °C** (Observation 3.2): **the core.**
10. **constant coefficient or not** (Observation 4.1): **the separator; Paper 402.**

Closing: **A thermocouple measures not a temperature but an integral between two junctions.With a constant Seebeck coefficient, $100-0$ °C and $500-400$ °C both give 4.100000 mV, but with a coefficient of $39+0.02T$ μV/°C they give 4.000000 and 4.800000 mV, 1.200000 times apart——the law of intermediate temperatures still holds with difference 0, and voltages add over intervals.With the reference junction actually at 25 °C but taken as 0 °C, a constant coefficient gives a reading error of 25.000000 everywhere, but a varying one gives 24.074286 at 100 °C, 21.912255 at 300 °C and 17.899160 at 800 °C——no single number corrects it.The separator is whether the Seebeck coefficient is constant or varies with temperature——"the temperature was measured with a thermocouple" does not say what was measured until one states the reference temperature and the coefficient's form.Placed among the earlier papers——Paper 402 showed an extra satellite needed for an unknown clock; this counts a voltage that is no temperature without a known reference junction.To be honest——coefficients are representative, and real tables, compensation circuits and generation are not treated.**

References

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