

Thermal Expansion Measurements: Background Correction

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June 24, 2015

This paper shows how to perform the background correction for thermal expansion measurements in the PPMS. This is an extension of the procedure presented in [1].

We start with the following notion: When we increase the temperature, the sample, with total length L , will expand, i. e. undergo a length change $S(T)$. This will move the capacitor plates closer together, so that we measure a length change $M(T)$. However, the part of the frame directly opposite to the sample will expand also, moving the capacitor plates away from each other and thus decrease the measured length change.¹ The effect is illustrated in Fig. 1. We call the length change of the frame the cell background $B_L(T)$ and *define* it by

$$M(T) = S(T) - B_L(T) \quad . \quad (1)$$

The index emphasizes that the cell background is a function of the length of the measured sample.

If we now measure a reference sample, e. g. high purity copper, of length L_0 with known thermal expansion coefficient $\alpha(T)$ and relative length change $\Lambda(T) = \int_0^T \alpha(T') dT'$, we know that the sample length change is $S(T) = \Lambda(T) \cdot L_0$ and can determine the background from

$$B_{L_0}(T) = \Lambda(T) \cdot L_0 - M_{L_0}(T) \quad . \quad (2)$$

The simple picture presented above is not complete because the assumption of a homogeneous cell is not correct. Differing materials are found in the form of the insulation washers (vespel) and the capacitor gap (vacuum). Since these features are located below the sample, one would expect their contributions to be independent of the sample length. Also, thermal gradients may introduce a significant background, which may have both sample length dependent and independent components. Thus, a better form for the background is

$$B_L(T) = B'(T) + B''(T) \cdot L \quad , \quad (3)$$

where $B'(T)$ and $B''(T)$ denote the sample length independent and dependent parts, respectively. The example measurements in Fig. 2 show that B_L is indeed a linear function of L , so that eq. (3) is a valid assumption.

¹The thermal expansion of the cell in general is assumed to cancel out because the cell is made of a single material (CuBe).

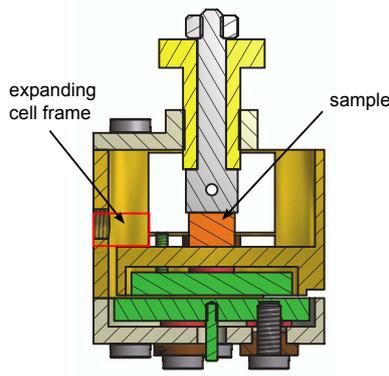


Figure 1: Origin of the cell background. Adapted from [1].

With this form, we need at least background measurements to determine the two curves in (3). For this, we measure two reference samples with different lengths L_1 and L_2 and calculate two backgrounds

$$B_{L_1}(T) = \Lambda(T) \cdot L_1 - M_{L_1}(T) \quad (4)$$

$$B_{L_2}(T) = \Lambda(T) \cdot L_2 - M_{L_2}(T) \quad . \quad (5)$$

Then, in order to get the background for a sample of arbitrary length L , we interpolate between our two backgrounds:

$$B_L(T) = (1 - x) \cdot B_{L_1}(T) + x \cdot B_{L_2}(T) \quad , \quad (6)$$

where $x = (L - L_1)/(L_2 - L_1)$. (By substituting (3) with $L = L_1$ and $L = L_2$ in (6), we can verify that this indeed yields (3), the background for arbitrary sample length L .)

Now that we know the background for our sample with length L , we can perform the correction and calculate the sample length change

$$S(T) = M(T) + B_L(T) \quad . \quad (7)$$

Finally, one may divide by the sample length to calculate the relative sample length change $\Delta L/L \equiv S(T)/L$, which is usually reported.

Figure 3 shows two examples for a background analysis. We observe that the cell background is always larger than the expansion of the reference sample, so that the measured signal $M(T)$ is negative. Also, the background depends strongly on the thermal history of the PPMS sample chamber, as can be seen in the different curves for warming and cooling. It is therefore important to always follow the same measurement sequence if the background calibration is to remain valid. The PPMS sequences for the measurements in Fig. 3 are given in listings 1 and 2.

References

- [1] R. Küchler et al., Rev. Sci Instr. **83** (2012)
- [2] I.-M. Pietsch, Bachelor's Thesis, U Göttingen (2012)

| Symbol | dimension | typical unit | description |
|-----------------|---------------------|---------------------|--|
| L | length | mm, cm | length of sample |
| L_0, L_1, L_2 | | | lengths of reference samples |
| $S(T)$ | length | 10^{-6} cm | length change of sample |
| $M(T)$ | | | measured length change |
| $B_L(T)$ | | | cell background |
| $\alpha(T)$ | temperature $^{-1}$ | 10^{-6} K $^{-1}$ | thermal expansion coeff. of reference sample |
| $\Lambda(T)$ | dimensionless | 10^{-6} | relative length change of reference sample |

Table 1: List of symbols.

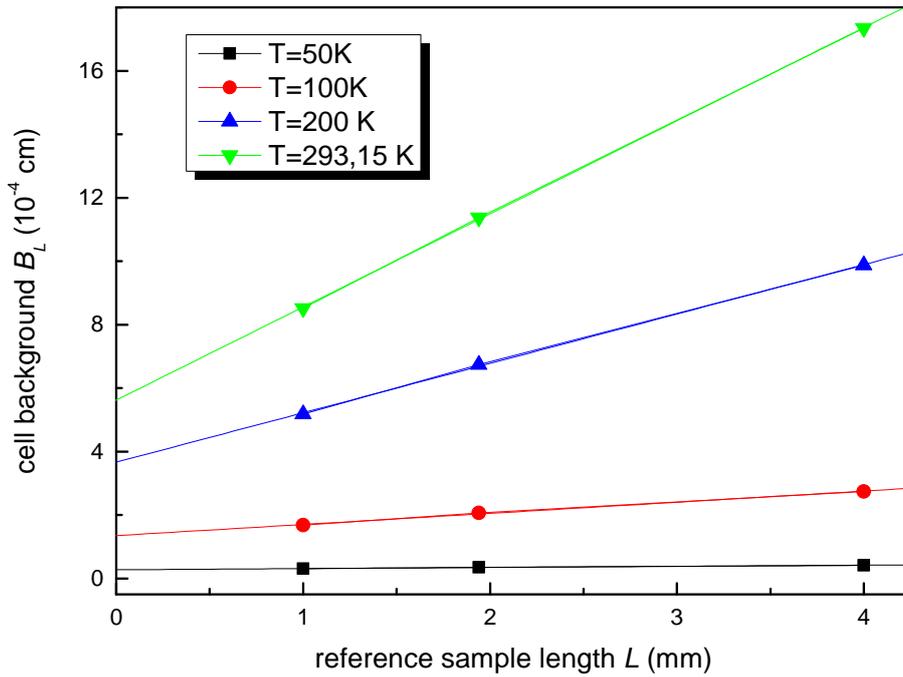


Figure 2: Cell background B_L for Cu reference samples of different lengths. From [2].

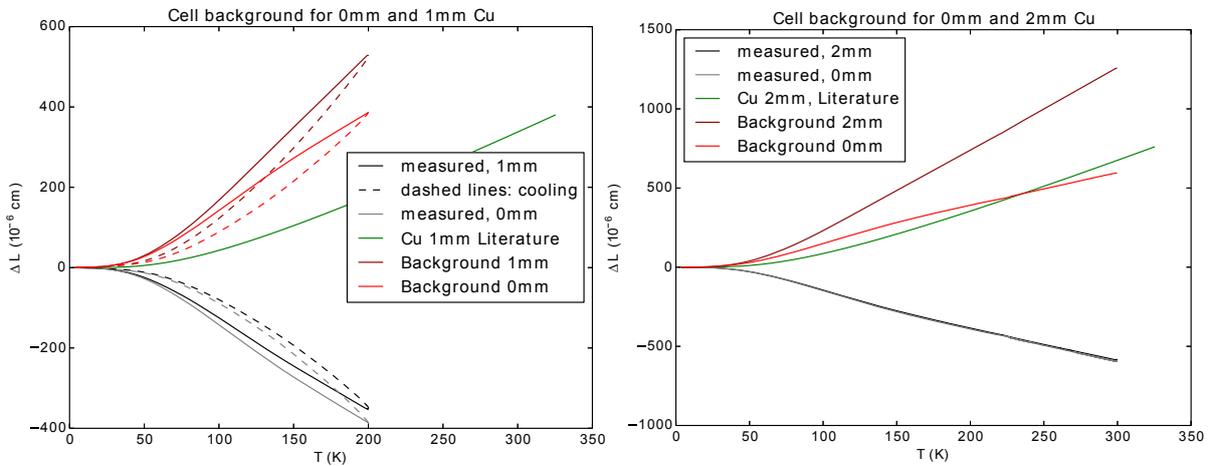


Figure 3: Example background measurements on Cu reference samples. The graphs show the measured length changes $M(T)$, the known length change $\Lambda(T) \cdot L$ from the literature and the calculated backgrounds $B(T)$. Left: PPMS2 in Göttingen, April 2014. Right: PPMS1 in Augsburg, May 2015.

```
##### auf 4K abkuehlen und 1 h thermalisieren
Set Temperature 4K at 15K/min. Fast Settle
Wait For Temperature, Delay 3300 secs, No Action
##### Aufwaermen: mit 0.3 K/min messen bis 200 K: 1 h thermalisieren
Set Advise Number 1
Wait For Temperature, Delay 300 secs, No Action
Set Temperature 200K at 0.3K/min. Fast Settle
Wait For Temperature, Delay 300 secs, No Action
Set Advise Number 2
##### zu 300 K und Ende
Set Temperature 300K at 12K/min. Fast Settle
```

Listing 1: A typical PPMS sequence for measuring thermal expansion. The Advise 1 (2) command starts (stops) data acquisition into a new file.

```

#####    auf 4K abkuehlen und 1 h thermalisieren
Set Temperature 4K at 15K/min. Fast Settle
Wait For Temperature, Delay 3300 secs, No Action
#####    Aufwaermen: mit 0.3 K/min messen bis 200 K: 1 h thermalisieren
Set Advise Number 1
Wait For Temperature, Delay 300 secs, No Action
Set Temperature 200K at 0.3K/min. Fast Settle
Wait For Temperature, Delay 300 secs, No Action
Set Advise Number 2
Wait For Temperature, Delay 3000 secs, No Action
#####    Abkuehlen: mit 0.3 K/min messen bis 4 K: 10 min warten
Set Advise Number 1
Wait For Temperature, Delay 300 secs, No Action
Set Temperature 4K at 0.3K/min. Fast Settle
Wait For Temperature, Delay 300 secs, No Action
Set Advise Number 2
#####    zu 300 K und Ende
Set Temperature 300K at 12K/min. Fast Settle

```

Listing 2: The sequence used to measure a background for both warming and cooling, as in Fig. 3 (left).