Uncertainty Budget for the Realisation of the Provisional Low Temperature Scale PLTS-2000 at PTB

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The Provisional Low Temperature Scale PLTS-2000 is defined by a polynomial p/MPa = f(T_{2000}/K) relating the ^{3}He melting pressure p to the temperature T_{2000} in the range from 0.9 mK to 1 K [1]. According to the definition of the PLTS-2000, for the *in situ* calibration of the pressure transducer four natural features on the ^{3}He melting curve may be used as fixed points of pressure and temperature: the minimum, the transition to the superfluid 'A' phase, the 'A to B' transition in the superfluid and the Néel transition in the solid. In this document, a complete uncertainty budget is presented for the realisation of the PLTS-2000 at the highest level of accuracy at PTB.

For realising the PLTS-2000, the melting pressure is measured using home-made capacitive diaphragm gauges as pressure sensors. The melting pressure must be measured *in situ* because for temperatures below the minimum, the pressure sensing line becomes blocked with solid ^{3}He. The parameters of the pressure sensors such as sensitivity, non-linearity, hysteresis, stability, and temperature dependence of the calibration have been determined using a quartz-oscillator pressure transducer and a pressure balance carrying a calibration against the national pressure standard [2]. These investigations were carried out at temperatures between 1 K and 1.5 K. The uncertainty component introduced by applying the pressure calibration of the sensor at 1.5 K down to temperatures of 1 mK, i.e. by the so-called temperature dependence of the pressure calibration, was estimated by recording the change of the reading of the sensor during cooling from 1.5 K down to a few mK for a pressure stabilised at a value slightly below that of the minimum.

The highest level of accuracy for the realisation of the PLTS-2000 is achieved by calibrating the pressure sensor at the natural features of the melting curve. The pressure values of these features cover the range from 2.93113 MPa to 3.43934 MPa. This is nearly half the pressure interval of the defining polynomial that extends up to 4 MPa. In the lowest temperature range of the PLTS-2000 near the phase transitions in ^{3}He, i.e. from 0.9 mK to 2.5 mK, the pressure sensor can be directly calibrated against the natural features using a linear interpolation between the pressure values from 3.43934 MPa to 3.43407 MPa resulting in a significantly reduced uncertainty of the scale realisation. To cover the whole range in pressure from 2.9 MPa to 4 MPa, we have applied a calibration of the pressure sensor against a quartz-oscillator pressure transducer that in turn was calibrated against the pressure balance. The uncertainty components caused by the hydrostatic head correction and the determination of the effective area of the pressure balance are eliminated by adjusting the resulting calibration to the pressure values at the natural features of the ^{3}He melting curve. Finally, the pressure calibration of the sensor is represented in form of a polynomial of second order

$$p = g(C) \ ,$$

where C is the corrected capacitance of the pressure sensor according to the formula

$$C = C_\mathrm{B} + \sum_{j=1}^{11} \delta C_j \ .$$

Here, C_B is the reading of the capacitance bridge, and δC_j are corrections to the reading, the expectation values of which are not necessarily equal to zero. In a second step, the temperature T_{2000} is calculated from

$$T_{2000} = f^{-1}(p) + \sum_{i=1}^{4} \delta T_i$$

where $f^{-1}(p)$ is the temperature value resulting from the inverse solution of the defining polynomial of the PLTS-2000 for a pressure value p at a selected branch below or above the minimum. The δT_i are corrections to $f^{-1}(p)$, the expectation values of which are equal to zero. In Table 1, the complete uncertainty budget for the realisation of the PLTS-2000 is given for selected temperatures.

References

1. "*Procè-Verbaux des Séances du Comité International des Poids et Mesures*", **68** (2001) p. 129

2. Schuster, G., Hoffmann, A., and Hechtfischer, D., "*Realisation of the temperature scale PLTS-2000 at PTB*", PTB, Braunschweig, PTB-ThEx-21, ISBN 3-89701-742-3, 2001

Table 1. Uncertainty budget for the realisation of the PLTS-2000 at PTB. Uncertainty values are in mK. (MPS melting-pressure sensor, MS measurement system)

Temperature / K		**0.001**	**0.015**	**0.25**	**0.65**	**1**
Uncertainty components Type B	**Source of uncertainty**					
u (δC_1)	Correction for the nonlinearity of the MPS	0.001	0.003	0.021	0.006	0.004
u (δC_2)	Mechanical stability of the MPS	0.001	0.004	0.032	0.009	0.006
u (δC_3)	Pressure calibration at the fixed points	0.001	0.001	0.021	0.010	0.011
u (δC_4)	Calibration against the quartz-oscillator pressure transducer and pressure balance	0.001	0.006	0.043	0.014	0.011
u (δC_5)	Instability of pressure control during calibration	0.001	0.003	0.021	0.006	0.004
u (δC_6)	Change of the head correction by temperature variation during calibration	0.001	0.001	0.004	0.001	0.001
u (δC_7)	Heating of the MPS by the excitation voltage	0.001	0.015	0.015	0.015	0.015
u (δC_8)	Temperature dependence of the dielectric susceptibility of the epoxy of the MPS	0.001	0.005	0.042	0.012	0.007
u (δC_9)	Capacitance bridge	0.003	0.003	0.021	0.006	0.004
u (δC_{10})	Temperature dependence of the pressure calibration	0.001	0.005	0.042	0.012	0.011
u (δC_{11})	^{4}He impurities	0.010	0.010	0.010	0.010	0.010
u (δT_1)	Temperature differences between the MS and the temperature sensor	0.005	0.005	0.005	0.005	0.005
u (δT_2)	Drift correction	0.005	0.005	0.005	0.005	0.005
u (δT_3)	Temperature differences between the MS and the MPS	0.005	0.005	0.005	0.005	0.005
u (δT_4)	Temperature differences in the MS	0.005	0.005	0.005	0.005	0.005
Type B components 1 to 10 combined		**0.005**	**0.019**	**0.092**	**0.032**	**0.027**
Type B components combined all		**0.015**	**0.023**	**0.093**	**0.035**	**0.030**
Type A uncertainty component		**0.005**	**0.005**	**0.005**	**0.005**	**0.005**
Combined standard uncertainty (k = 1)		**0.016**	**0.024**	**0.093**	**0.036**	**0.031**
Expanded standard uncertainty (k = 2)		**0.031**	**0.048**	**0.186**	**0.071**	**0.061**