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EU dissemination of the provisional ultra-low-temperature scale, PLTS-2000

R. Rusby[a,]*, D. Head[a], D. Cousins[a], S. Schöttl[a], H. Godfrin[b], Yu.M. Bunkov[b], R.E. Rapp[b], F. Gay[b], M. Meschke[b], C. Lusher[c], J. Li[c], B. Cowan[c], J. Saunders[c], A. Casey[c], Dm. Shvarts[c], V. Mikheev[c,1], J. Pekola[d], K. Gloos[d], P. Hernandez[e], S. Triquenaux[b], M. de Groot[f], A. Peruzzi[f], R. Jochemsen[g], A. Chinchure[g], E. van Heumen[g], G.E. de Groot[g], W. Bosch[h], F. Mathu[h], J. Flokstra[i], D. Veldhuis[i], Y. Hermier[j], L. Pitre[j], A. Vergé[j], F. Benhalima[j], B. Fellmuth[k], J. Engert[k]

[a] *CBTLM, National Physical Laboratory, Teddington TW11 0LW, UK*
[b] *CNRS-CRTBT, Grenoble 38042, France*
[c] *Physics Department, Royal Holloway College, University of London, London, UK*
[d] *Physics Department, University of Jyväskylä, Jyväskylä 40351, Finland*
[e] *Advanced Technology Department, Air Liquide, Sassenage 38360, France*
[f] *NMi van Swinden Laboratorium, P.O. Box 654, Delft, AR 2600, The Netherlands*
[g] *Kamerlingh Onnes Laboratorium, Universiteit Leiden, P.O. Box 9504, Leiden, RA 2300, The Netherlands*
[h] *Hightech Development Leiden, P.O. Box 691, Leiden, AR 2300, The Netherlands*
[i] *Universiteit Twente, Technische Natuurkunde, P.O. Box 217, Enschede, AE 7500, The Netherlands*
[j] *BNM-INM, CNAM, 75141 Paris Cedex 03, France*
[k] *Physikalisch-Technische Bundesanstalt, D-10587 Berlin 10, Germany*

Abstract

Following the introduction of the provisional low-temperature scale from 0.9 mK to 1K, PLTS-2000, there is a need for primary and secondary thermometers and fixed points, which can disseminate the scale to users. This paper reports on the progress, within the EU collaborative project 'ULT Dissemination', in the development and evaluation of several devices with associated instrumentation. Principal among them are a current-sensing noise thermometer, a CMN thermometer adapted for industrial use, a Coulomb blockade thermometer, a second-sound thermometer, a ^{3}He melting pressure thermometer for a direct realisation of the PLTS-2000. A superconductive reference device has also been developed, as a replacement for the NBS SRM-768 which is no longer available.

Keywords: Temperature scale; Thermometry; PLTS-2000

1. Introduction

The provisional low-temperature-scale from 0.9 mK to 1 K, PLTS-2000, provides the basis for reliable temperature measurement over the wide range in which commercial dilution refrigerators operate. It is defined in terms of the melting pressure of ^{3}He and extends down to the superfluid and Néel feature temperatures [1]. Following its introduction there is a need for primary and secondary thermometers and fixed points to disseminate the scale to users. The European project 'ULT Dissemination' was started in January 2000 to develop several devices with their associated instrumentation. These are now briefly described.

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*Corresponding author. Tel.: +44-20-89437036; fax: +44-20-89436755.

E-mail address: richard.rusby@npl.co.uk (R. Rusby).

[1] Permanent address: Oxford Instruments Superconductivity, Old Station Way, Eynsham, Witney, Oxon, OX29 4TL, UK.

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2. Thermometers and devices

A current sensing noise thermometer (CSNT) is under development, in which a DC SQUID is used to measure the thermal noise current in a resistor and T is obtained using the Nyquist formula. The thermometer is fast and can be used over the temperature range from 4.2 K to below 1 mK. The CSNT can in principle measure T absolutely: alternatively if the gain is measured at one point it can be used as a secondary thermometer without further calibration. A commercial DC SQUID is being used as the preamplifier, and a precision of 1% should be obtainable in 10 s [2].

A Coulomb blockade thermometer (CBT) uses the non-linear current–voltage characteristics of an array of tunnel junctions [3]. For N junctions the half-width of the dip in conductance is proportional to Nk_BT/e. A number of Coulomb blockade sensors have been constructed with optimum parameters and tests down to 80 mK have shown satisfactory results. CBTs are being developed for use down to 10 mK, with projected accuracies of $<0.5\%$ between 4.2 and 0.1 K, 2% down to 30 mK and 5% below this. The devices have high immunity to magnetic fields, although to date this has only been demonstrated down to 50 mK [4].

Pt-powder and ^{3}He NMR thermometers and electronics, with low-T pre-amplifiers, have been built and tested. The high-sensitivity, very low power, spectrometer consists of a room temperature differential amplifier, and a radio-frequency bridge detection of the small change of impedance of a NMR tank circuit (Q-meter configuration). The system has been tested by measuring the susceptibility of bulk liquid ^{3}He, a benchmark system where problems are encountered due to poor spin diffusion at high T and Kapitza resistance at low T. The measurements were made as a function of pressure (0–3 MPa) and temperature (down to 5 mK).

A second spectrometer has been developed with a 4.2 K pre-amplifier, which allows the measurements to be extended towards 1 K where the signal is small. The noise and gain of this system have been tested at 4.2 K.

A rugged CMN magnetic thermometer has been designed and built, with the aim of providing good transferability for interpolating a temperature scale. It has been shielded against stray magnetic fields using a superconducting niobium shield. External fields up to 50 mT were applied to the devices without any observable change of the measured values. It is currently undergoing trials at Air Liquide.

The second-sound thermometer (SST) uses the strong T-dependence of the velocity of the second sound in ^{3}He–^{4}He mixtures. The velocity is obtained from the acoustic resonance spectra in a closed cavity. A simple relationship then exists between the resonance frequencies, the dimensions of the cavity and the speed of the sound propagation [5].

The SST cell is sealed at room temperature with a 1% mixture of ^{3}He in ^{4}He, under pressure so that near 4.2 K liquid condenses and fills a cylindrical acoustic resonator chamber. Comparison with the ^{3}He melting pressure demonstrates its self-consistency of the model describing T as a function of the speed of the second sound. This was mostly within 0.1 mK [5].

A self-contained ^{3}He melting pressure thermometer is being developed, based on a cylindrical pressure gauge [6] with good linearity of pressure versus inverse capacitance. The readout electronics is based on a tunnel diode oscillator circuit.

In addition to using thermometers for disseminating temperature scales, it is useful to have access to fixed points against which the thermometers can be checked or calibrated. An important part of the present project has been to develop a Superconductive Reference Device, the SRD1000, using samples with transitions between 15 mK (tungsten) and 1.2 K (aluminium) [7].

3. Evaluation

The development phase of the project is nearing completion. In the second phase several partners will evaluate these various thermometers, with a view to establishing their potential for application in ULT experiments. In addition, some ruthenium oxide resistive sensors are under investigation at PTB.

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