PTB news

Metrology
Technology
Services
Cooperation

01.1

Consistent Low-Temperature Scale Adopted

The International Committee for Weights and Measures (CIPM) has adopted the PLTS-2000 as a low-temperature scale. For the first time the CIPM now has an internationally valid and consistent temperature scale for thermometry in the millikelvin range. The new scale utilises the melting pressure of helium-3 for temperature measurement and is based, among other things, on measurements performed by PTB.

With defined temperature fixed points, standard thermometers and interpolation procedures, the **I**nternational **T**emperature **S**cale of 1990 (ITS-90) enabled consistent temperature measurements to be performed down to the ITS-90 lower limit of 0,65 K. For temperatures below that the situation was confusing until now. Scientists could choose among several scales leading to different temperature values, in particular, below 6 mK. This unsatisfactory situation has now been resolved by adopting a low-temperature scale for the range from 0,9 mK to 1 K.

The new scale is based on the melting-pressure curve of ^{3}He. The new scale specifies the relation between the melting-pressure p and the temperature T by a polynomial function $p(T)$.

The specification of $p(T)$ is based on precise measurements using primary thermometers such as noise and nuclear-orientation thermometers. These devices rely on fundamental physical relations and are irrespective of material properties. The measurements were performed at the US metrology institute NIST, at the University of Florida and at PTB in Berlin (cf. PTB*news* 97.1). At tempeatures above approximately 0,3 K the new scale is identical with the PTB scale. In the lower temperature range the measured values are not yet in perfect agreement, and a suitable average has been taken in order to minimize deviations from the ideal thermodynamic temperature scale. This explains why the new scale is named "**P**rovisional **L**ow **T**emperature **S**cale of 2000" (PLTS-2000).

In spite of the uncertainty remaining, the adoption of a unified scale and its world-wide application represent a great step forward because measurements will be immediately comparable in future. In case further investigations should give rise to slight corrections of the scale, older measurement results can be readily converted into more precise values.

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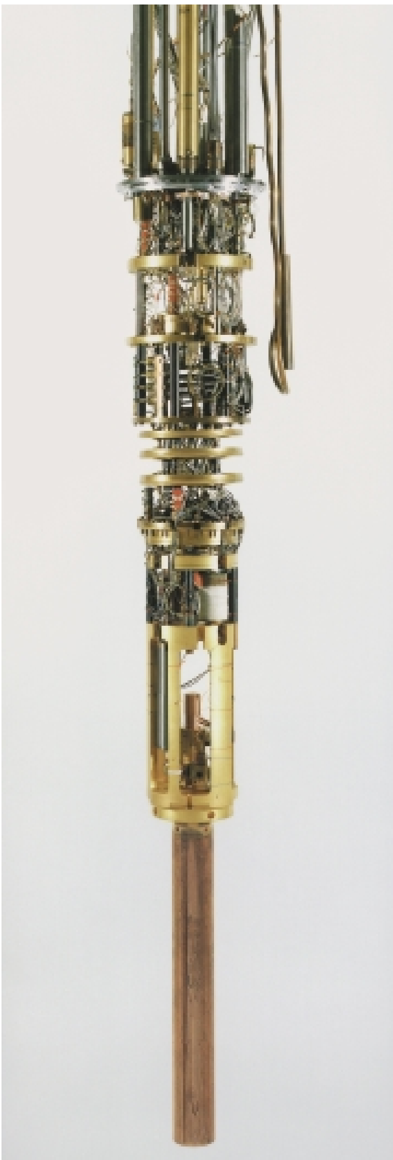

Cryostat insert of PTB used to generate very low temperatures. The nuclear demagnetisation stage at the lower end consists of about 2 kg of high-purity copper. The initial magnetic induction is 8 T. Final temperatures of 65 μK can be generated and long-term temperatures of 300 μK can be maintained.

Software Test Centre Accredited

At PTB software is not only a tool for carrying out tests but itself an artefact to test. Therefore a software test center had been established at PTB which is open to customers. The centre's objective is to ensure confidence in the correct and reliable functioning of systems which essentially rely on software. The accreditation process by DATECH (Deutsche Akkreditierungsstelle Technik e. V.) has been successfully concluded.

Users of software actually take certain risks which must not be neglected. For example, the correct implementation of software, i. e. in compliance with the functional requirements, is a serious challenge. If the software product is to be easy to handle and readily adaptable the risks involved may go as far as outright manipulation. The task then is to minimize the (residual) risk that will always remain. For this reason PTB established a software test centre, which has now been accredited as a test laboratory confirming the test centre's competence. The accreditation covers testing of software for functionality, reliability, safety and usability on the one hand and testing according to ergonomic criteria on the other.

Besides individual testing of software (packages) for calibration and measuring instrumentation, the test centre's performance spectrum includes risk prevention assessments of the manufacturer's software development processes, based on audits at the manufacturer's location.

The services of the software test centre are offered to the laboratories of PTB and other government institutions, other test and calibration laboratories, manufacturers of measuring and test equipment and, in particular, to small- and medium-sized enterprises.

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Smallest Density Inhomogeneities in Quartz Glass

Photolithography requires lenses made of quartz glass of the highest homogeneity. PTB has developed a new method to determine deviations in density based on a simple concept. Detection of smallest density differences in quartz glass is now possible with this new method.

With the increasing miniaturization of integrated electronic components, the precision requirements for the optical components in photolithography are growing as well: Quartz glass lenses of highly precise shape and extremely homogeneous refractive index are required for the objectives. The refractive index of high-purity quartz glass is essentially determined by the structure of the glass and is correlated with the density ρ_Q of the glass. For quartz glass, a difference in the density $\Delta\rho_Q$ of 10^{-5} ρ_Q corresponds to a difference of the refractive index of $1{,}5 \cdot 10^{-6}$. Such minute differences can hardly be detected by optical means. Therefore PTB was asked to develop a more precise detection method by direct density measurements. Only samples of roughly 1 cm^3 were available. For samples of that size small differences in density can only be detected with a flotation method. Two (or more) samples are contained simultaneously in a liquid, the density of which ρ_{Fl} is very similar to the density ρ_Q of the samples. By varying the pressure inside the liquid the density ρ_{Fl} can be adjusted to match the density of each sample ρ_Q, i. e. $\rho_{Fl} = \rho_Q$. According to this special case of Archimedes' principle the sample, for which the equation holds – and only that sample – will float freely in the liquid.

The flotation apparatus varies the liquid pressure by adjusting two parameters: the hydrostatic pressure (exerted by an additional vessel connected with the measuring vessel) and the temperature. A small time constant of temperature equilibrium is obtained with special cuvettes. The detection limit for samples of cuboidal shape amounts to $1 \cdot 10^{-6}$ ρ_Q. First measurements on five quartz glass samples yielded relative density differences of up to $3 \cdot 10^{-5}$ (corresponding to differences in the refractive index of $5 \cdot 10^{-6}$). The measurement uncertainty achieved was $5 \cdot 10^{-6}$ ρ_Q ($k = 2$).

The flotation method allows measuring smallest differences in the density of quartz glass samples. The sample volumes are approximately 1 cm^3.

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Refractive Index – Traceability with Reference Liquids

PTB now offers certified reference liquids to test and calibrate refractometer equipment used in industrial instrumentation and measurement processing. With the new reference liquids testing and calibrating is much easier and more precise.

Up to now, refractive indices are traced with precision glass prisms the customer has to supply to PTB. This procedure is difficult and expensive. Alternatively, PTB can now offer certified reference liquids for this purpose filled in special phials for one-time use. These reference liquids have special properties: they are sufficiently stable with respect to their chemical composition, non-hazardous in terms of occupational medicine and easy to apply. Furthermore, they cover a range of refractive indices required in practical applications and enabled the data to be circulated with a sufficiently small uncertainty.

The following hydrocarbons are liquid at ambient temperature and have been found to be well suited for use as reference liquids: n-heptane ($n_D = 1{,}388$), isooctane ($n_D = 1{,}392$), methylcyclohexane ($n_D = 1{,}423$), cyclohexane ($n_D = 1{,}427$), tetrachlorethylene ($n_D = 1{,}508$). n_D denotes the refractive index at spectral line D of the mercury-vapour lamp. At PTB, the refractive indices are calibrated for six wavelengths in the visible light range between 404,7 nm and 643,8 nm, with an uncertainty of 10^{-5}. Using these reference liquids measurements of refractive indices with a refractometer can be traced back over almost the entire spectral range of visible light. Dispersion correction of the refractive index is not necessary as long as the wavelength applied in the measurement coincides with the wavelength declared on the calibration certificate to within ± 0,1 nm. Such small uncertainties require a temperature stability during calibration within ± 0,01 K around a well-defined value.

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Prismatic sample cell to measure the refractive index with appliance to mount temperature detectors and some phials with reference liquids.

Support for EUV Lithography: Metrology with 13 nm Radiation

The steady drive towards miniaturization in the semiconductor engineering industry calls for photolithographic processing with ever decreasing radiation wavelengths. This constitutes a new challenge for metrology, too. At present, extreme ultraviolet (EUV) lithography, a "next generation" technology, is starting to be realized. In support of this development, PTB is making extensive use of synchrotron radiation at wavelengths around 13 nm.

The structure width of memory chips for computers is one standard example of the progress semiconductor technology is making. During the last three decades, the width has been reduced by a factor of 2 every five years. According to the annual "International Technology Roadmap for Semiconductors", the guideline for development work, this trend is to be continued for at least another fifteen years until structure widths are down to about 20 nm.

Photolithography with EUV radiation and electron-beam projection lithography are considered as the most promising techniques to produce semiconductor structure widths of 70 nm and less in the future. Photolithography technology requires "at wavelength" metrology with 13 nm radiation on a large scale. In order to meet this demand PTB is making extensive use of several measuring facilities in its synchrotron radiation laboratory at the Berlin electron storage ring BESSY II. At present, the main tasks are:

- to determine the reflectivity and homogeneity of Mo/Si multilayer mirrors to be used for projection of mask structures onto wafers with typical relative uncertainties of 0,2 %
- to investigate the degradation of EUV optical elements, filters and detectors subjected to intense EUV irradiation
- to develop methods for the characterization of optical EUV projection systems
- to calibrate measuring instruments such as spectrographs and filter-photodiode systems to be used for the characterization of EUV radiation sources with uncertainties down to 1 %.

Work in this field is carried out in close collaboration with industry and research institutes in the frame of national and international funding programmes.

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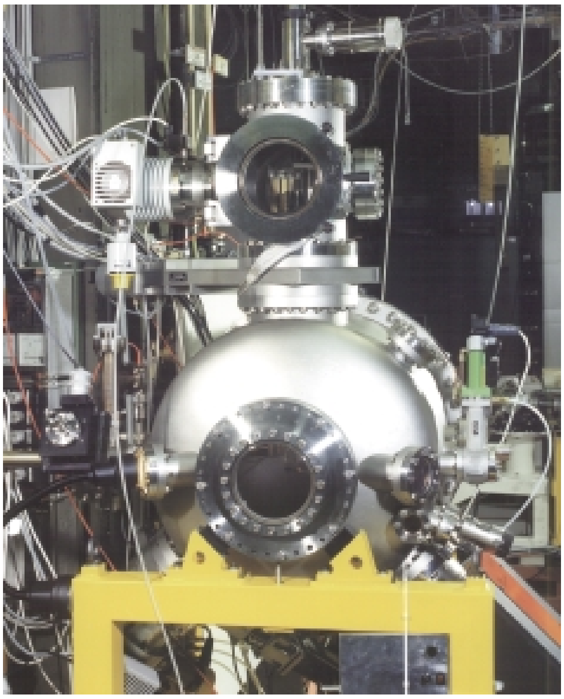


Reflectometer used by PTB for the characterisation of optical components (mirrors, gratings, filters) with monochromatized synchrotron radiation

News from the Editor

PTB*news* enters its 6th year of appearance with the present issue. In the past five years this periodical scientific news bulletin has established itself among the other PTB publications. It has become well-accepted as shown by the large number of inquiries and responses received to many of the topics reported on. PTB*news* is currently circulated to more than 6000 addresses world-wide.

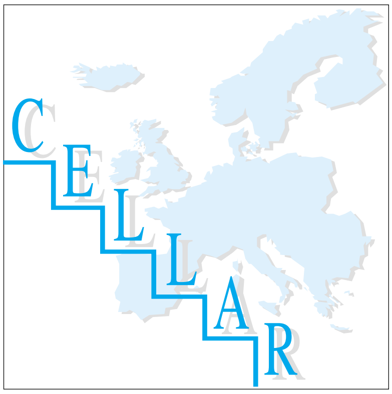
Beginning with this volume PTB*news* will also be doubly available on the internet: At the address **www.ptb.de**, the latest issue and an archive containing all previous issues can be found in the area "publications/download". All issues can be downloaded as pdf documents. Totally new is that, in addition, all articles from the PTB*news* can now be found under "publications/periodicals" in html format as well.

With the new year the editorial board has changed. The editor-in-chief of the past editions, Prof. Dr. Burkhard Wende, has passed the position to Dr. Dr. Jens Simon, the public relations spokesperson of the PTB. In effect, the editorial office, previously run by Monika Korte in Berlin, has been relocated to Braunschweig. In addition, Dr. Fritz Riehle, editor and member of the very first board, is leaving to take on new assignments. The board-of-editors wish to thank the outgoing members for five years of invaluable editorial work and their engagement in effectively making PTBnews what it has become today.

European Network of Underground Laboratories

PTB has signed an agreement to co-operate in a network of European laboratories with access to underground facilities for ultra low-level radioactivity and dosimetry measurements.

Measurements of very low count rates from radioactive decays are necessary for basic and applied physics, technology and life sciences. They require an almost "radiation free" environment. At ground level these measurements are often hampered by the background of cosmic radiation. Best possible suppression of cosmic radiation, especially of muons, can only be achieved in experiments performed far below ground level. For this purpose, PTB operates an underground laboratory at the Asse salt mine near Braunschweig. Located at 925 m under the surface in a pure rock salt surrounding there are very low specific activities of primordial radio-nuclides such as ^{40}K present in the lab. Hence, the ambient dose rate at this facility is only about 1 % of that at ground level, the muon flux density is reduced by even more than five orders of magnitude and negligible for most applications. PTB's laboratory has successfully participated in several international comparative measurements of sensitive detector systems. It is equipped with a facility for calibrating dose and dose-rate meters at low dose rates and with shielded low-background germanium detector systems dedicated to measure low radioactivities by γ-ray spectrometry.



Collaboration of **E**uropean **L**ow-level underground **La**bo**r**atories

PTB and six other institutes, IRMM (Belgium), IAEA (Austria), LN Gran Sasso (Italy), University of Iceland, LSCE (France), MPI Heidelberg and VKTA Rossendorf (Germany) have recently founded a Collaboration of European Underground Laboratories ("CELLAR"). This collaboration aims to stimulate investigations in applied physics, to co-ordinate measurement programs and comparative measurements as well as to provide easier access to underground facilities for science and industry.

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PTB*news* 01.1
English edition
March 2001

Published by
Physikalisch-Technische
Bundesanstalt (PTB)
Braunschweig and Berlin
Germany

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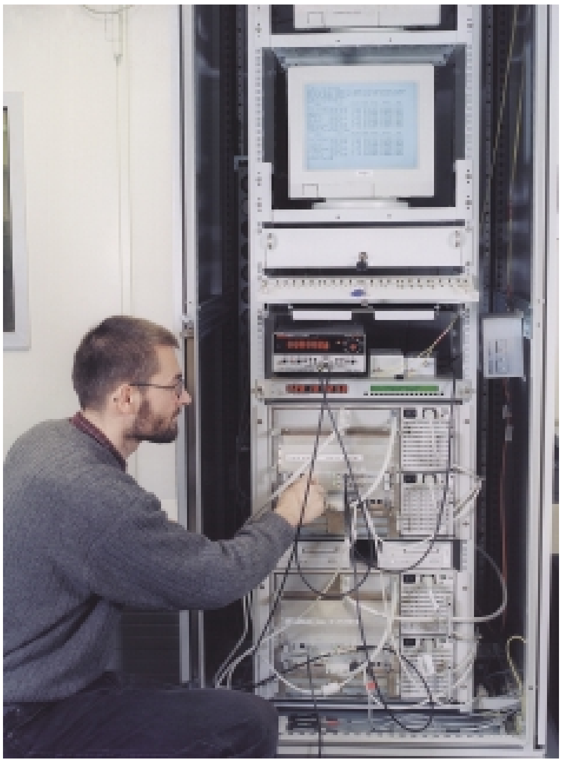
PTB Time in the Internet

Time signals from the atomic clocks of the PTB are synchronizing an increasing number of computer systems around the world via the internet: Over 2,5 million times per day external computers of scientific institutions and industrial companies, of small-scale enterprises and private persons access the two public time servers of the PTB. The jitter of the time signals delivered is typically only 20 µs.

In information technology (e. g. for process control, dating of measurement data or recording of events), it is frequently necessary to synchronize server systems with each other and to link up their operating system time with the **U**niversal **T**ime **C**oordinated (UTC). The **N**etwork **T**ime **P**rotocol (NTP) is a standard protocol established on the internet. It is the obvious protocol for this purpose and suitable for setting up a hierarchic system of time servers. PTB operates two servers for this purpose under the internet addresses **ptbtime1.ptb.de** and **ptbtime2.ptb.de**. For practical use of the NTP time information a software package is needed to support the NTP protocol. Suitable software is available for all common operating systems. This service supplements the previous time transmission service by means of DCF77 radio clocks or GPS receivers.



Time server of the PTB

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