PTB news

Scientific Newsletter

3
2024

Three times a year, PTB News provides topical information from the varied spectrum of activities of the Physikalisch-Technische Bundesanstalt (PTB) consisting of fundamental research, legal metrology and PTB's variou

SCIENTIFIC NEWS

TECHNOLOGY TRANSFER

MISCELLANEOUS

Measuring altitude differences with atomic clocks

Optical clocks open up new applications in geodesy

Especially interesting for
- geodesy

In Munich, time passes faster than in Braunschweig. Physically speaking, this is a fact according to Albert Einstein's general theory of relativity. The difference is due to the fact that Munich is located at a higher altitude. One second in a million years – the difference is minuscule, but can be measured very accurately using optical atomic clocks. In a cooperation project, PTB has demonstrated that it is possible to carry out chronometric altitude measurements with optical clocks.

Time passes more slowly closer to a massive body (such as the Earth). This relativistic effect is one of the core predictions of the general theory of relativity and has been experimentally confirmed since the middle of the last century. The differences in the frequences of optical atomic clocks, which are linked to each other via optical fibers, can be used to measure the differences in the Earth's gravitational field directly and very accurately. Chronometric leveling facilitates a wealth of novel applications in geodesy. It is, for example, possible to resolve differences between the elevation networks of different countries, which can be particularly large if there is no direct land connection (e.g., between islands and the mainland). The sea level could also be monitored more accurately by improving the network of tide gauges. For short distances, chronometric leveling has already demonstrated uncertainties of a few centimeters.

PTB has developed a transportable clock based on laser-cooled strontium atoms that can be used for chronometric leveling. In addition, PTB operates an optical fiber link to compare optical clocks in cooperation with several European partners. Together with the Max Planck Institute of Quantum Optics (MPQ) in Garching and Leibniz University Hannover, PTB has measured the physical altitude difference between MPQ and PTB by using this optical fiber link. For this purpose, the frequency of the transportable clock was initially compared to another strontium clock at

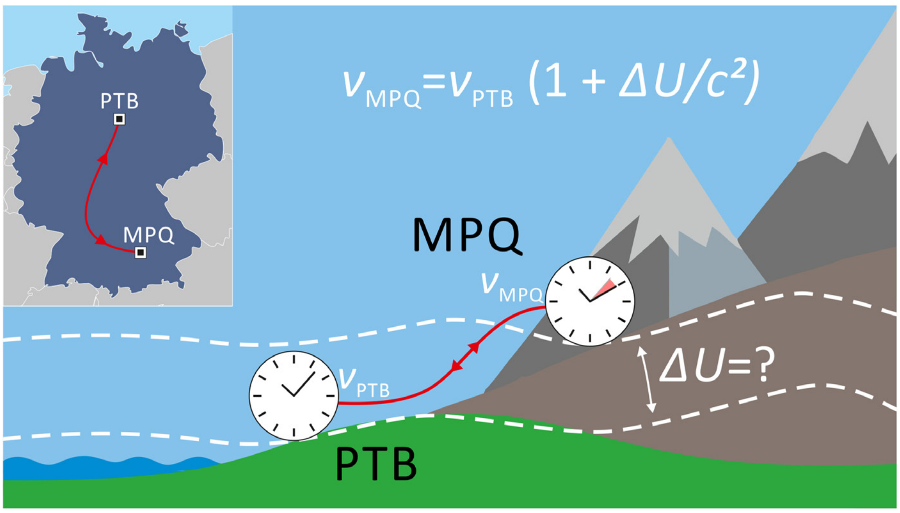

Illustration of a chronometric altitude measurement. The clocks at PTB in Braunschweig and at MPQ in Munich are located at different depths in the gravitational field of the Earth and therefore run at different speeds. The difference between the frequencies ν is measured via an optical fiber link (small figure). The altitude difference or potential difference ΔU is related to the measured frequencies by the speed of light c.

PTB and then transported to MPQ. There, it was again compared to the clock at PTB via an optical fiber link to reveal to what extent the frequencies had changed relative to each other. The two clocks were then compared at PTB once again to make sure that nothing had changed apart from the relativistic redshift. The measurement data was used to determine the altitude difference that amounted to approximately 400 meters with an uncertainty of 27 centimeters. Additionally, the chronometric measurement agrees with the value from established conventional methods.

Although this method is not as accurate as conventional procedures yet, it has shown that chronometric altitude measurements are practically feasible with optical clocks, thus paving the way for applications in geodesy. If portable optical clocks can also achieve the accuracy of laboratory setups, chronometric altitude measurements will even exceed the accuracy of current geodetic methods of measurement. ▪

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Scientific publication

J. Grotti et al.: Long-distance chronometric leveling with a portable optical clock. Phys. Rev. Appl. 21, L061001 (2024),
DOI: 10.1103/PhysRevApplied.21.L061001

Hollow reference particles

Size and concentration of reference particles for extracellular vesicles traceably measured for the first time

Especially interesting for

- nanomedicine

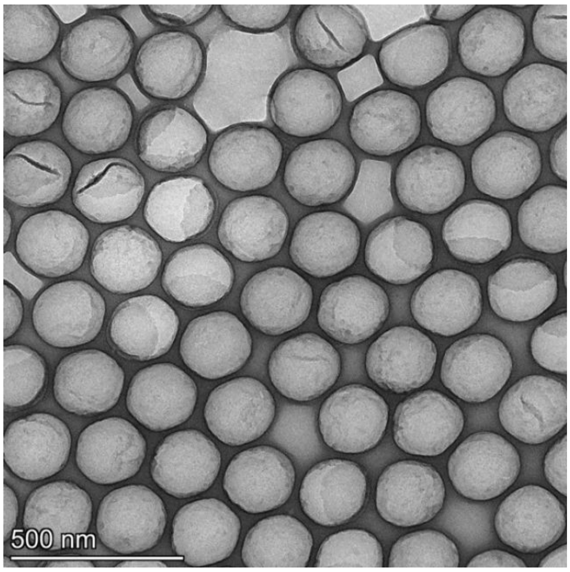
Extracellular vesicles are membrane particles that are present in body fluids. They are potential biomarkers for illnesses such as cancer or inflammatory and cardiovascular diseases. Synthetic reference particles allow measurement procedures to be quantitatively compared for the first time. PTB has measured these particles using synchrotron radiation.

In medical research, extracellular vesicles (EVs) are of great interest because they are released by all cell types, and their biochemical composition, concentration and function depend on the respective illness, making them potentially ideal biomarkers for those illnesses. Until now, however, it had not been possible to determine the size and concentration of the particles with sufficient accuracy.

Flow cytometry is among the frequently applied optical measurement methods. It is used to measure to which degree EVs scatter light in liquid. However, comparing different measurements quantitatively was previously impossible because traceable calibration methods were not available for the instruments used in clinical practice.

Hollow organosilica beads (HOBs) are potentially suitable as reference particles for calibrating optical measuring devices. They consist of a porous organosilica shell with a defined thickness, which has formed around a silica core. This core is chemically dissolved in the fabrication process so that only the shell remains. The optical properties of HOBs are similar to those of EVs. As part of a European metrology research project, PTB has used synchrotron radiation to contribute to characterizing the size of HOBs accurately by means of small-angle X-ray scattering. For the first time, it has been possible to determine the size and concentration of such particles in a way that is traceable to the International System of Units. Four different types of HOBs with diameters from 200 nm to 500 nm were characterized in the project. By varying the thickness of their shells, it is possible to synthesize HOBs that have very different optical properties and many different sizes. In this way, reference particles can be customized for extracellular vesicles of different size ranges.

In the future, even smaller particles with a diameter of less than 200 nm will be focussed on, as advances in cytometer technology will enable the clinical analysis of ever smaller EVs. ▪



Electron microscopy image of a sample of hollow organosilica beads

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Scientific publication

J. Deumer et al.: Traceable characterization of hollow organosilica beads as potential reference materials for extracellular vesicle measurements with optical techniques. Discover Nano 19, 14 (2024),
DOI: 10.1186/s11671-024-03956-3

Skyrmions: On the way to application

Optical procedure for reading, writing and deleting microscopic magnetic vortices

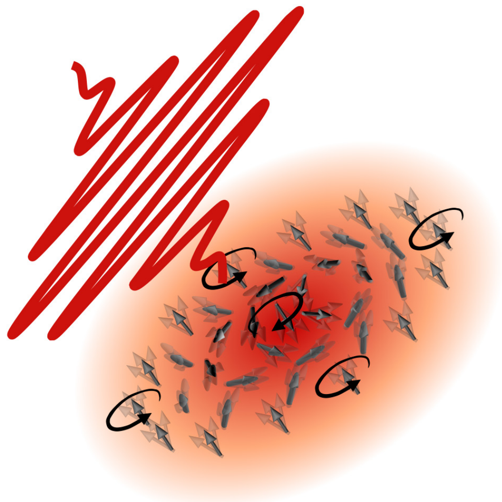
Especially interesting for

- research (magnetism, femtosecond measurement technique)

Local vortices in the spin structure of magnetic materials, known as skyrmions, are considered promising candidates for novel memory and logic components. The ability to precisely generate, erase, and read out skyrmions is a critical requirement for such applications. PTB has developed a purely optical procedure that allows exactly this. In this method, skyrmions are locally manipulated with pulsed laser light. This is an important step toward practical applications.

Due to their small dimensions in the nanometer range and their high stability, skyrmions, which are microscopically small magnetic vortices, are not only interesting for fundamental research but also for future memory and logic components. They occur in materials such as MnSi and FeCoSi. In general, skyrmions in this material class are stable in a very small parameter range, which results in significant limitations for potential applications. However, previous research has shown that skyrmions can also exist outside this range when the material is in the so-called non-equilibrium state.

This phenomenon is used at PTB to selectively create and delete skyrmions with pulsed laser light. When skyrmions are generated optically, the laser places the sample in the non-equilibrium state, in which the skyrmions exist in a wide range of parameters. The reverse process is also possible, where the skyrmions are extinguished in the focal area of the laser beam. In this case, the laser excitation resets the sample to its thermal equilibrium state in which the skyrmions no longer exist. The presence of skyrmions is read out by means of their characteristic magnetization dynamics. These dynamics are excited with the laser and measured in a time-resolved manner using magneto-optical techniques. This approach realized at PTB implemented a purely optical process for the manipulation of skyrmions.



Skyrmions are locally written and deleted using laser excitation. Their characteristic magnetization dynamics enable optical detection after the writing and deletion process.

To better understand how skyrmions are optically generated and deleted, their dependence on the laser power was investigated and position-resolved measurements were taken. Comparisons between measurements and simulations of various skyrmion distributions allowed conclusions on the limit parameters for optical writing and deletion processes as well as the spatial expansion of the generated structures. The investigations demonstrated that the optically generated structures are highly stable, which is an important precondition for their technological applicability. ▪

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Scientific publication

J. Kalin et al.: Optical creation and annihilation of skyrmion patches in a chiral magnet. Phys. Rev. Appl. 21, 034065 (2024), DOI: 10.1103/PhysRevApplied. 21.034065

In-situ rotary table calibration

Reduced three-rosette method to determine deviations of rotary tables

Especially interesting for

- calibration laboratories
- rotary table manufacturers
- gear manufacturers

The deviations of rotary tables can be directly measured on coordinate measuring machines (CMMs) in all six degrees of freedom by means of a self-calibrating procedure using a ball plate. A new concept at PTB is intended to significantly reduce the required number of ball measurements at the specified angular resolution. This enables economical measurements at a higher angular resolution and without noteworthy drifts. For angular resolutions of 5°, a novel ball plate that has been adapted to the method has been manufactured at PTB. The measurement uncertainty will increase only slightly in comparison with the previous method.

When rotationally symmetric workpieces, such as gears, are measured on coordinate measuring machines or machine tools, rotary tables are frequently used. Their rotary guides contribute to the uncertainty of the measurement result. For highly accurate measurements, it is therefore essential to determine these deviations and to subsequently correct them numerically. For this purpose, the so-called three-rosette method determines the deviations of the rotary table in all six degrees of freedom at angular grid points that are regularly distributed over a complete rotation of the rotary table. The resolution of the identified rotary table deviations is determined by the number of balls. Determining the deviations at smaller angular steps requires a ball plate with more balls, which would soon exceed the scope in which it makes sense to realize such ball plates. In addition, the measuring time increases quadratically with the number of balls, which not only makes the method uneconomical, but also unreliable due to drift effects.

Due to a reduced three-rosette method that has been recently developed at PTB, it is no longer necessary to attach balls to every position on the angular grid as specified by the desired resolution. To apply the patent-pending method, a novel ball plate with 12 balls was manufactured. This plate allows the deviations of the rotary table to be measured at 72 reference points, i.e., in 5° steps. The balls' positions have been optimized in terms of low measurement uncertainty. For this reason, the overall measurement uncertainty increases only slightly, by approximately 10 % to 20 %, in comparison with complete method. ▪


Ball plate for the reduced three-rosette method with 12 irregularly arranged balls

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Scientific publication
F. Keller, M. Stein: A reduced self-calibrating method for rotary table error motions. Meas. Sci. Technol. 34, 065015 (2023),
DOI: 10.1088/1361-6501/acc265

Sunlight from the lab

Globally unique equipment for measuring the power output of solar modules

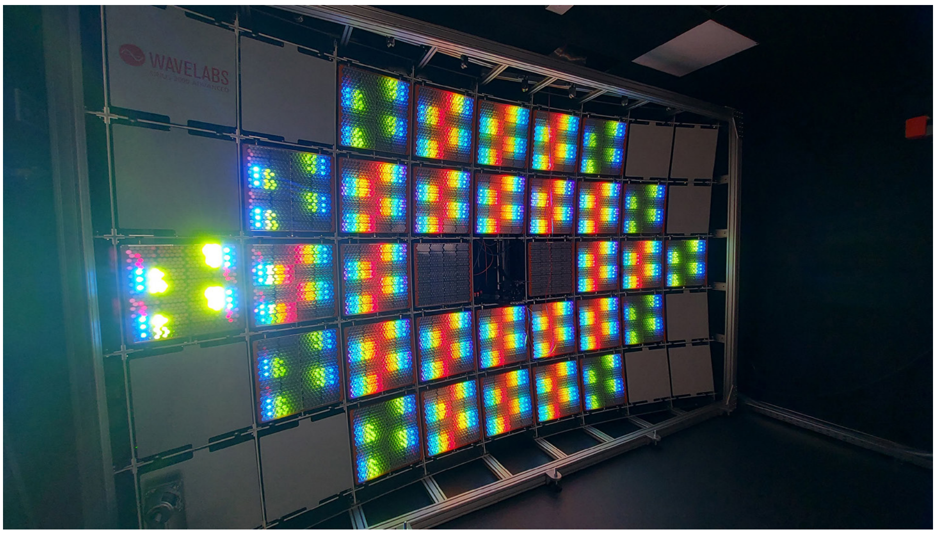
Especially interesting for
- photovoltaics

PTB's solar simulator, which can traceably measure the output of solar modules, has been completely redesigned. It outperforms its predecessor in terms of all the important properties: Its LED lamps have more spectral colors, generate a more uniform light field and can illuminate larger modules.

Today, approximately 80 % of all solar cells produced worldwide can be traced to PTB's reference system because PTB has been offering calibrations of the greatest accuracy in this field for a long time. Since 2021, PTB has expanded its calibration offer from individual solar cells to whole solar modules. The new solar simulator is the most important piece of the puzzle in this offer – and the world's best in terms of its properties.

The EU is currently planning to introduce energy labels for solar modules, similar to those used on fridges and other electronic devices. With its measuring facilities, PTB is prepared for the increasing demand for calibrations in this field and is conducting projects in pre-normative research. These projects are intended to pave the way for a standardized yield estimation of PV modules.

The retrofitted measurement setup covers a spectral range from 330 nm to 1200 nm for these tasks, and it contains a total of 19 000 LED lamps in 26 different colors. The light field of the solar simulator, with a maximum power of 1300 W/m^2, is 240 cm × 140 cm in size and varies less than 1 % over the whole area. These specifications allow PTB to calibrate the electrical properties of a solar module, such as



The LED solar simulator can illuminate modules up to a size of 140 cm × 240 cm. Its 26 LED lamps with different colors cover the entire sensitivity range of solar modules, from UV light to near-infrared light.

its maximum power, short-circuit current and open-circuit voltage at standard test conditions, with the lowest measurement uncertainty in the world.

Another new feature of the solar simulator in comparison with its predecessor is the double-sided light source (one LED light source at each end of the room), which enables us to illuminate the front and the back of the solar module. This is required for the bifacial solar modules that have been available on the market for several years and whose rear side can also generate electricity.

The solar simulator is part of the Photovoltaics Competence Center at PTB, which offers a unique technical infrastructure providing realistic measurements of the greatest accuracy and making use of both artificial and natural sunlight for these measurements. ▪

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Improved diagnosis of breast tumors

New method for the fast evaluation of optical mammograms

Especially interesting for

- diagnosing tumors
- optical mammography

Diffuse optical imaging allows the characterization of physiological parameters of breast tumors. The perturbation theory models previously used in the evaluation provided accurate results only for small tumors. A new method for rapidly interpreting optical mammograms makes it possible to analyze larger tumors with less uncertainty.

Diffuse optical mammography is a technique for investigating breast composition. The principal advantages of this non-invasive technique are the ability to quantify the concentrations of oxyhemoglobin, deoxyhemoglobin, water and collagen, to semi-quantitatively characterize blood flow and to visualize the enrichment of a contrast agent in breast lesions. An appropriate model is necessary to quantify the optical properties of breast tumors for a variety of applications. For a considerable period of time, the so-called perturbation method has constituted one of the most significant tools for the characterization of lesions in optical mammography. This method is particularly effective due to its theoretical simplicity and flexibility.

When scanning the breast, picosecond laser pulses are broadened as a result of the strong scattering of light in the tissue. If the exiting light pulse is analyzed at the position of a tumor, the optical properties of the tumor can be determined using perturbation theory. However, the application of the perturbation theory has so far been limited to the first and second order due to the considerable computational effort involved, which only provides valid results for small tumors. In a joint research project, Freie Universität Berlin, California State University and PTB have developed an efficient method that allows the application of higher orders.

The absorption can now be computed for larger tumors, as demonstrated in experiments on tissue-like phantoms. The investigations carried out have shown that the current method can be used directly in clinical practice to speed up analysis. The time it takes to analyze a single time signal was reduced from eight hours to four seconds using the perturbation theory up to the third order with the novel method. The application of the proposed method is not limited to breast cancer. It can also be extended to fluorescence emissions in biological tissues and optical tomography, for example, in brain tumors. ▪

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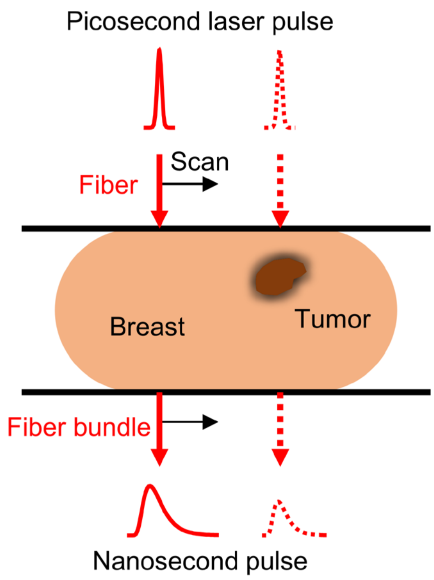
Scientific publication

B. Wassermann, R. A. Jishi, D. Grosenick: Efficient algorithm to calculate the optical properties of breast tumors by high-order perturbation theory. JOSA A 40, 1882 (2023), DOI: 10.1364/JOSAA.498799



Optical images of the breast are obtained in transmission geometry by a scanning procedure. At each scan position, the breast is transilluminated by picosecond laser pulses at multiple wavelengths. Photons travelling through the breast are multiply scattered. A small fraction of photons is absorbed, particularly by hemoglobin in the blood vessels. The analysis of the temporal distribution of the photons collected by a fiber bundle yields information about the tissue composition such as the physiological properties of tumors.

Measuring radon reliably

First-ever SI-traceable calibration of radon activity concentration in ambient air

Especially interesting for

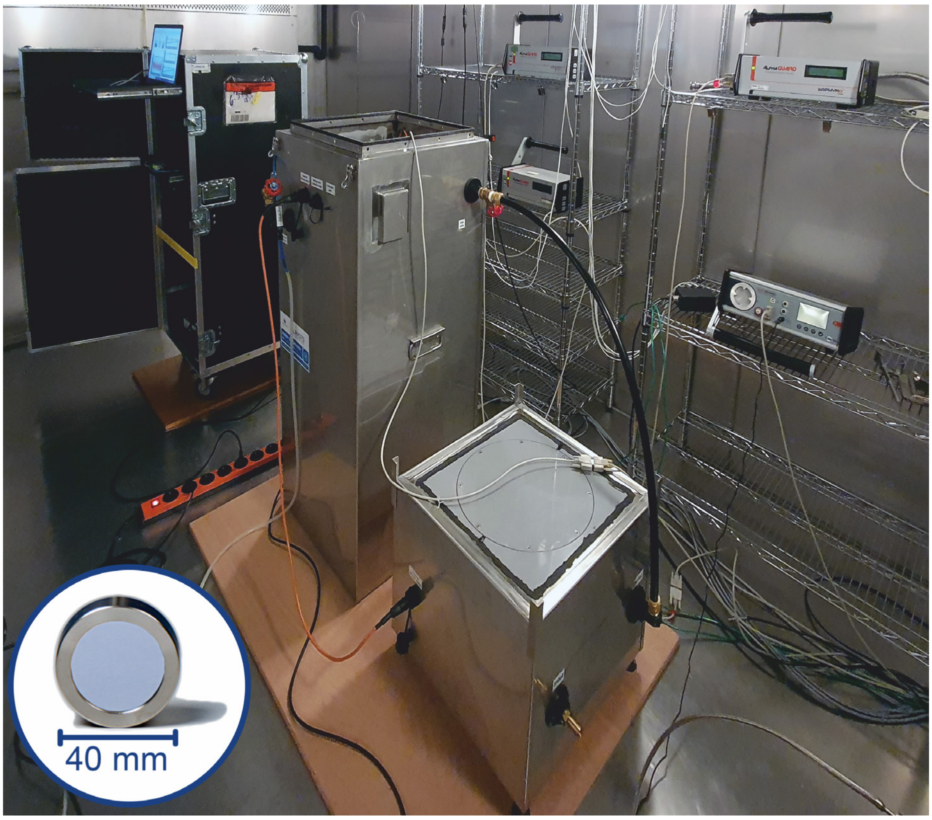
- climate observation
- radiation protection

Radon is responsible for a large part of natural radiation exposure. However, it is useful as a so-called tracer in climate observation and modeling. At PTB, two new SI-traceable calibration capabilities have been developed for extremely low radon activity concentrations, with the potential for mobile use.

In Germany, the radioactive noble gas radon (Rn-222) is mainly found in the low mountain ranges of southern Germany, where the subsoil contains granite, for example. If it accumulates in poorly ventilated rooms, it poses a health risk. People who ventilate their homes less frequently and use better insulation to save energy need to be aware of this fact and should rely on quality-assured measurements when testing for radon.

However, radon also has positive aspects: As it undergoes the same exchange processes between the soil and the atmosphere as greenhouse gases, but is not bound via photosynthesis like CO_2, for example, it is suitable as a tracer to test various models of greenhouse gas fluxes (radon tracer method).

An entirely new instrument was developed in the traceRadon EMPIR project: It consists of a commercial silicon-based detector that has been coated with a thin layer of vaporized Ra-226. This makes it a radon source and detector at the same time (integrated radon source/detector, IRSD). Even in the range of extremely low natural radon activity concentrations, it can measure with high accuracy. Novel evaluation algorithms, which can even determine the release of one radon atom per second (approx. 2 µBq · s^{-1}) on average within a few hours' integration time with an uncertainty of 4 % ($k = 2$), were among the items that were designed and implemented for this purpose. In the future, the IRSD will be used to calibrate radon monitors continuously, automatically and traceably, even in the field and under changing climatic conditions.



The new transfer standards for outdoor air radon activity concentrations: ANSTO 200 L in the foreground (on the wooden plate) and ARMON v2 in the background (black transport box) in PTB's climate chamber. Inset: the new Integrated Radon Source/Detector (IRSD)

As a novel 226-Ra source, the IRSD was used in PTB's climate chamber to calibrate two measuring systems developed in the project under non-dynamic conditions at outdoor air activity concentrations (~20 Bq · m^{-3}). They are now available as secondary transfer standards.

Thanks to the new traceability methods developed by PTB, metrologically validated (i.e., comparable and quality-assured) data on radon activity concentrations in the atmosphere and on radon fluxes in soil are available to the climate monitoring networks for the first time.

One of the aims of an upcoming European project (EURAMET/EPM/RadonNET) is to develop cost-effective, mass-produced detectors that can be interconnected to form smart networks. This will be an important contribution to healthy and energetically sustainable smart cities. Another project (EURATOM/NuClim) will develop the use of the radon tracer method further and combine it with studies on the quantification of pollutants and their effects on marine ecosystems as well as providing qualified background baseline measurements and derived models. ▪

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Scientific publication

S. Röttger et al.: Evolution of traceable radon emanation sources from MBq to few Bq. Appl. Radiat. Isot. 196, 110726 (2023), DOI: 10.1016/j.apradiso.2023.110726

Secure electronic voting

Especially interesting for

- IT service companies
- cybersecurity

In electronic voting systems such as opinion polls or voting by secret ballot, networks are used to anonymously transfer the data of several senders (such as voters) to a receiver. The data package transfer to the receiver has to remain transparently comprehensible for the senders, but the voting behavior must not be traceable for others. This is effected by means of an anonymization network, which is characterized by layered encryption and decryption as well as the permutation of the order of the data at a large number of network nodes. In this way, receivers cannot trace digital data to a particular sender. However, for senders, the data packages are always transparent. The novelty about this network is the fact that voters can change their vote without risking their anonymity at any time until the deadline expires. (Technology Offer 516) ▪

(Image: otello-stpdc / stock-adobe.com)

Advantages

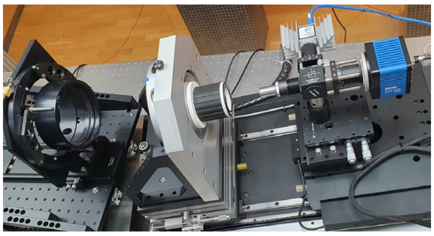
- confidential voting
- vote modifiable before ballot count

Quality of optical systems

Especially interesting for

- DAkkS (German accreditation body) calibration laboratories
- calibration and traceability in MTF measurements

A modulation transfer function (MTF) is used to describe the imaging quality of an optical system. A new procedure of PTB – the irradiance-based imaging quality assessment (IBIQA) – improves the determination of an MTF for any optical system. This reduces measurement uncertainties and also allows the MTF to be determined by means of non-linear detectors. The method consists in performing a grey-scale value analysis of individual pixels at various exposure times and evaluating them. This has positive effects on the optical quality control of the transmission function, traceability and feasibility of measurement comparisons. (Technology Offer 553) ▪



An optical system (center of photo) being measured with sensors (right)

Advantages

- reduced measurement uncertainty
- extension to non-linear detectors
- optimization of optical quality control

Detecting alpha particles from a distance

Especially interesting for

- emergency response
- the nuclear industry
- control points like borders, ports and airports

Conventional detection techniques for alpha radiation require a direct interaction of the alpha particles with the detector material, which limits the detection range to merely a few centimeters. PTB has developed radioluminescence detection systems which rely on quartzglass and polymethyl methacrylate (PMMA) Fresnel lenses, allowing the indirect detection of alpha radiation at distances of more than 2 meters. The relevant signal is maximized, and ambient light is simultaneously suppressed by efficient light filtering and using low-noise photo multipliers. PTB's prototype can detect alpha radiation from a safe distance without putting staff members at risk or contaminating the equipment.(Technology Offer 7106) ▪

Lens-based radioluminescence detection system

Advantages

- remote mapping of contaminations
- mobile use
- quick switching between spectral ranges

Contact person for questions about technology transfer

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Awards and News

Annette Röttger

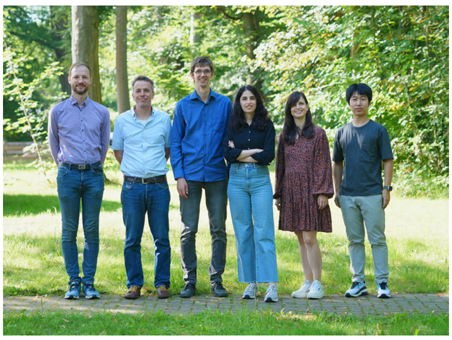
Annette Röttger, a member of PTB's Presidential Board, has been a member of the *Board of Directors* (BoD) of EURAMET, Europe's regional metrology organization, since June 2024. The body with a total of nine members is responsible for the administration and strategic orientation of EURAMET. Annette Röttger was elected to the board at the last EURAMET General Assembly.

Andreas Bauch

Andreas Bauch, a scientist in Department 4.4 *Time and Frequency* has received the 2024 Marcel Ecabert Award. With this prize, the European Frequency and Time Forum (EFTF) is honoring his excellent lifetime achievements in the field of time and frequency measurements. Although Mr. Bauch has retired, he is currently still connected to PTB and his team through a smaller-scale contract.

Holger Großhans

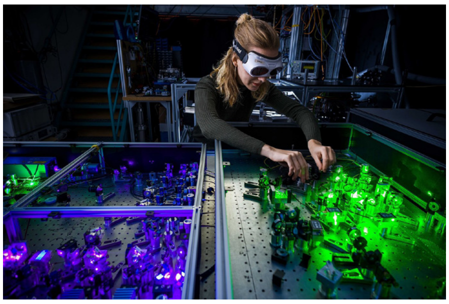
Holger Großhans from Department 3.5 *Explosion Protection in Energy Technology* has successfully acquired an ERC grant from the EU for the second time. Together with his team, Mr. Großhans has developed a method which will be used to prevent dangerous dust explosions in the future. The ERC Proof of Concept grant encompasses funding amounting to 150,000 euros which the team intends to primarily invest in technology transfer.



Holger Großhans (second from left) surrounded by his team

Collaborative Research Center extended

Since its launch in 2016, the Collaborative Research Center "Designed Quantum States of Matter" (DQ-mat) has evolved into the German headquarters for quantum metrology and is a global leader in this field. The German Research Foundation (DFG) has now approved an extension of four additional years and is supporting the Collaborative Research Center with roughly 10 million euros in funding. The participants from Leibniz University Hannover, the DLR Institute for Satellite Geodesy and Inertial Sensing (Hannover) and PTB are working on the next generation of quantum sensors – for more sensitive, faster and even higher-resolution measuring instruments such as atomic clocks or atomic interferometers.
(Contact: Piet Schmidt, +49 531-592-4700, piet.schmidt@quantummetrology.de)



DQ-mat scientists perform research on the quantum sensors of tomorrow in laser laboratories like this. (Photo: Hosan/LUH)

Certificates and test reports now exclusively digital

Since June 2024, the Conformity Assessment Body of PTB has been issuing all certificates and test reports for explosion-protected equipment exclusively in the form of PDF documents with a digital seal. The documents encompass EC type-examination certificates with the appurtenant data sheets, declarations of conformity, test reports as well as IECEx test reports. Using the qualified digital signature, the recipients of the documents can verify the issuer, PTB, and clearly identify any later changes to the data.
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High-tech Incubator

Ceremonial key handover at the opening event

A new site for the technology transfer of quantum technologies opened in the former Rollei factory buildings on 10 April 2024: Quantum Valley Lower Saxony's High-tech Incubator (QVLS-HTI). The roughly 500 m² of office and laboratory space is where 11 start-ups and excellent research institutions regularly convene to share ideas. It is planned that established businesses will also join them in the future. QVLS-HTI pools funding from the German federal government (Federal Ministry of Education and Research) and two federal state ministries (Ministry for Science and Culture; Ministry for Economics, Mobility, Building and Digitalization – both of Lower Saxony) as well as the expertise of PTB, TU Braunschweig and Leibniz University Hannover.
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Imprint
PTB News 3/2024, English edition,
Issue November 2024, ISSN 1611-163X
The PTB News is published three times each year in a German as well as in an English edition and can be subscribed to free of charge.
Subscription form: www.ptb.de > English Version > Publications > PTB News > Subscribe the PTB News
Publisher: Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin
Editors: Andreas Barthel, Martin Götz, Alexander Gottwald, Tobias Klein, Christian Lisdat, Norbert Löwa, Erika Schow, Jens Simon (verantwortlich)
(responsible)
Layout: Volker Käbert, Alberto Parra del Riego (concept)
Translation: PTB Translation Office
Editorial Office: Press and Information Office, PTB, Bundesallee 100, D-38116 Braunschweig,
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Federal Ministry for Economic Affairs and Climate Action

The Physikalisch-Technische Bundesanstalt, Germany's national metrology institute, is a scientific and technical higher federal authority falling within the competence of the Federal Ministry for Economic Affairs and Climate Action.