PTB MITTEILUNGEN 2

TECHNICAL AND SCIENTIFIC JOURNAL OF THE PHYSIKALISCH-TECHNISCHE BUNDESANSTALT 2012

125 Jahre genau 1887 – 2012

PTR/PTB: 125 Years of Metrological Research

PTB MITTEILUNGEN
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125 Jahre genau
1887 - 2012

Special Journal for the Economy and Science
Official Information Bulletin of the
Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin

Advance copy from: 122nd volume, issue 2, June 2012

Contents

Title picture:

Together with Werner von Siemens and others, Hermann von Helmholtz campaigned personally for the foundation of the PTR and became its first president from 1888 to 1894.

Imprint

The *PTB-Mitteilungen* are the metrological specialist journal and official information bulletin of the Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin. As a specialist journal, the *PTB-Mitteilungen* publishes scientific articles on metrological subjects from PTB's fields of activity. As an official information bulletin, the journal stands in a long tradition which goes back to the beginnings of the Physikalisch-Technische Reichsanstalt (founded in 1887).

Publisher
Wirtschaftsverlag NW
Verlag für neue Wissenschaft GmbH
Bürgermeister-Smidt-Str. 74–76,
27568 Bremerhaven
Postfach 10 11 10, 27511 Bremerhaven
Internet: www.nw-verlag.de
E-Mail: info@nw-verlag.de

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Frequency of publication and prices
The *PTB-Mitteilungen* are published four times each year. An annual subscription costs € 55.00, one issue costs € 16.00, plus postage costs. The journal can be obtained from bookshops or from the publisher. Cancellations of orders must be made to the publisher in writing at least three months before the end of a calendar year.

Printed in Germany ISSN 0030-834X

Preface

The "Physikalisch-Technische Reichsanstalt" (PTR) and the "Physikalisch-Technische Bundesanstalt" (PTB) have always considered the completion of a quarter century to be an anniversary year and have commemorated it accordingly. Therefore, the imminent 125th birthday of the PTR/PTB will be commemorated, and the present issue of the *PTB-Mitteilungen* is making a contribution. Of the anniversaries mentioned, this is a special one. For the first time after the end of World War II, it is possible for PTB to present itself completely united – though at two sites (in Braunschweig and in Berlin), but one entity both internally and externally, committed to the sovereign mandate, and responsible for the uniformity of metrology and its further development through its own research and development and the resulting services.

Thus, PTB today indeed still sees itself in the spirit of the founding fathers of the PTR, Werner von Siemens and Hermann von Helmholtz, upon whose persistent actions, and supported by high-ranking representatives from politics, science and economy, the *"Reichstag" (Imperial Diet)* decided to grant the PTR an annual budget for the first time on 28 March 1887. Thus the foundation was laid for the first major research institution, with an impressive success story in the late 19^{th} and the early 20^{th} centuries. The heyday of the PTR in the first decades is linked to the names of distinguished scientists as staff members of PTR and active members of the Kuratorium (Advisory Board) such as, e.g., Wilhelm (Willy) Wien, Friedrich Kohlrausch, Walter Nernst, Emil Warburg, Walter Bothe, Albert Einstein and Max Planck – to name just a few. After the incorporation of the *Reichsanstalt für Maß und Gewichte (Imperial Weights and Measures Office)* in 1923, the PTR encompassed a range of tasks as it still exists at PTB today.

The taking over of governmental power by the National Socialists in 1933 also marked the end of the heyday of the PTR, and at the end of World War II, the PTR was virtually broken up and dispersed across all the states outside of Berlin. Thanks to the unbroken idealism of some former staff members of the PTR, the selfless commitment of some scientists outside of the PTR (Max von Laue must be named here in first place) and the generous support of the British military government, parts of the old PTR were able to take up their work again in Braunschweig as early as 1947, even though it was under the most difficult conditions. Already before the founding of the Federal Republic of Germany in 1949, the PTR became the *"Physikalisch-Technische Anstalt des Vereinigten Wirtschaftsgebiets" (Physical and Technical Institute of the United Economic Territory* – PTA) which, in 1950, finally received the designation *"Physikalisch-Technische Bundesanstalt"* (PTB).

Further milestones towards today's PTB (extracts of which are also reported on in the present issue) were the unification of PTB with the "Rest-PTR", re-emerged in Berlin, and its integration into PTB as "Berlin Institute", the taking over of the site of the dissolved *"Amt für Standardisierung, Messwesen und Warenprüfung" (Office for Standardisation, Metrology and Quality Control* – ASMW) of the former German Democratic Republic (GDR) in Berlin-Friedrichshagen after the reunification of Germany in 1989 and finally, 10 years later, the consolidation to the two sites: in Braunschweig and in Berlin-Charlottenburg.

As a result of this variable history, today PTB is 125 years young, optimally set up and prepared for the challenges of the coming years. I am convinced that – if the framework conditions allow this – the good wishes which are addressed on the occasion of such an anniversary will be fulfilled.

Prof. Dr. Ernst O. Göbel
President of PTB from 1995 to 2011

The Intention

Wolfgang Buck

To give birth to an institution whose complexity and significance has – averaged over the 125 years of its history – always increased, many capable heads and favourable framework conditions are necessary. To avoid having development break off in critical times, personalities are needed who are convinced of their mission and can inspire others. Basically, just a few of such personalities would suffice – but one needs them precisely then when circumstances demand it.

The birth of an institution itself is such a critical time. And in the same way as the development of German metrology for length and weight would not be conceivable without the Berlin astronomer Wilhelm Foerster, the *Physikalisch-Technische Reichsanstalt (Imperial Physical Technical Institute* – PTR) would not exist without the natural scientist and entrepreneur Werner von Siemens. With his memoranda, he provided the rationale – which was insightful also for politics – for the imperative necessity of such an institute, which others, such as Hermann von Helmholtz, filled with content. He offered the German Empire his private premises and the partial financing of the construction costs from an inheritance when politics had entangled itself in its diverse competencies. And he had a vision of what Germany needed in order to catch up with the prosperous industrial nations England and France.

Werner Siemens – not yet ennobled in the early 1880s – was deeply impressed by the progress made in natural science. *"Research in natural science always forms the secure base of technical progress, and the industry of a country will never acquire nor maintain an internationally leading position if the same is not simultaneously at the pinnacle of the progress made in natural science"*, he wrote in his recommendation dated April 1883, which he enclosed with his memorandum for the *"founding of an institute for the experimental advancement of exact natural science and precision engineering"* dated 16 of June of the same year and addressed to the Government of Prussia. His belief in the virtue of natural science goes even further than being just the *"basis for technical progress"*. In 1886, he professes in a lecture to the *Assembly of German Natural Scientists and Physicians* his idealism that *"the light of science penetrating the entire human society battles effectively against demeaning superstitions and corruptive fanaticism – these great enemies of humanity – so that we can continue to establish the era of the natural sciences with proud joy and in the sure confidence that humanity will be provided with moral and material conditions that are better than they ever were and still are today."*

Above:
Werner von Siemens, 1887, drawing by Ismael Gentz

Picture on the right:
The initials of the PTR

Werner Siemens was convinced of the natural sciences not only as a scientist and inventor. As an entrepreneur, he wanted to convert the findings gained into technical applications and exploit them commercially – to the benefit of the aspiring industrial and exporting nation of Germany. To this end, he needed in the "precompetitive" phase – if *"the operation is not profitable in private enterprise because, due to great difficulties and costs, no prospect of direct financial success whatsoever nor direct increase in the productive efficiency is to be expected"* – the support of a state scientific-technical institute – thus stated also in the memorandum of 1883. For him and other entrepreneurs of the rapidly growing electrical industry in Germany, *"fundamental electrical measurement standards are urgently needed"*; this is something for which the *Kaiserliche Normaleichungs-Kommission (Imperial Commission for the Verification of Material Standards)* – responsible for metrology – was not at all equipped.

In his memorandum dated 20 March 1884, in which he finally offers the German Emperor a *"contribution of abt. ½ million marks"* because his plan of founding the PTR *"cannot be implemented in this way in the necessary scope"* (note: this was limited to Prussia), he finally presents national arguments to which the addressee (the German Emperor) is known to be receptive: *"The Empire would gain significant material and ideal advantages from a natural science institute in the way it is planned. In the current competition of the nations, that country will have a distinct advantage* *which treads new paths first and which will be the first to develop industrial branches on the basis of these paths. [...] Almost without exception, it is the natural scientific findings – often of a very unimpressive nature – which open such new paths and create or revitalize important branches of industry. Whether the discovery of a new natural scientific fact is technically exploitable is usually not discovered until its complete and systematic processing – i. e., often after a long period of time. Therefore, scientific progress must not be dependent on material interests.*"

The intention of Werner Siemens and his fellow campaigners was the founding of a state-financed, university-external, major research institution – *"the first of its kind in Germany"*, as Federal Chancellor Angela Merkel asserted on 12 September 2007 in Berlin, at the annual meeting of the *Helmholtz-Gemeinschaft (Helmholtz Association)* – which is committed to fundamental research free from material interests and supports industry with current problems, among other things, with "measurement standards" and testing. Thus, the *Physikalisch-Technische Reichsanstalt* came into existence on 28 March 1887 with the adoption of the budget 1887/1888 by the *Reichsamt des Inneren (Imperial Office of the Interior)*, composed of a physical and a technical division in accordance with the basic intention. *"The idea seemed to be a good one – as today, there are many university-external research institutions"*, Angela Merkel thus stated approvingly. Recently, these institutions have joined forces under the name of the co-initiator and first president of the PTR, Hermann von Helmholtz. The PTR with its spectrum of tasks and PTB as its successor have, however, remained unique and their mandate – meanwhile greatly expanded and defined more precisely, but always oriented towards Siemens' vision – is today anchored in the Basic Constitutional Law of Germany.

The intention of the present issue of the *PTB-Mitteilungen* is to let the path of Siemens' vision shine through the entire course of history with all its facts and events. It is not the intention, however, to write a new history of the PTR and PTB, because a series of monographs have already been written and published on this subject by competent authors; these are listed at the end of this issue and are warmly recommended for reading pleasure (see page 68).

In the foreground, events and achievements will be presented – lined up along the timeline – in order to convey to the reader a feeling for the turbulence of some eras and also for the interim stagnation. This listing is enriched with biographical notes by the persons concerned because – as everywhere – institutions live by the individuals that shape and support them. All this information is kept very brief due to readability, in order to encourage the reader to procure further knowledge on his own as desired in the literature or on the Internet. These "text snippets" were written by many colleagues from all areas of PTB who, at this point, I would like to warmly thank for their support. Their names can be found at the end of this issue.

The explanation of individual, especially important steps and developments in the past 125 years has been given complete double-page spreads which interrupt the run of the timeline. Here, colleagues have presented and analysed backgrounds and trends in development from scientific history and from important fields of activity of PTB – a warm thank you to them, too! It begins with the personality of the first president and *"Reichskanzler der Wissenschaft" (Imperial Chancellor of Science)* Hermann von Helmholtz, followed by a report on the most spectacular success in the art of scientific experimentation of the PTR – the precise determination of the spectrum of blackbody radiation, which led Max Planck to his radiation formula and, thus, to the birth of quantum theory. The reason for the investigations made by the PTR was the need for a more precise standard for luminous intensity – to decide which type of street lighting in Berlin would be more economical: electricity, or with gas.

The *Kuratorium (Advisory Board)*, then as now filled with important representatives from science and industry, is a decisive element for determining the course of the institute and representing its concerns vis-à-vis politics and the public. President Warburg set the PTR on a new future track as early as before World War I by turning to new physics, through new sources of money and by a new division structure which still holds today. Under President Nernst it was possible to incorporate the classic metrology of weights and measures. The time of National Socialism and the time of World War II were characterized by a general decline of science in Germany. For the PTR, too, there was no escape from this.

The zero hour thereafter compelled – again due to the given political situation – a separate development in both German post-war countries. The commitment of both systems to legal metrology brought them into contact with one another through detours via international organizations like the OIML. German reunification made the mutual reorientation of metrology towards the challenges of the future possible. This was particularly visible at PTB's site in Berlin – both in the eastern part and in the western part of the city. The response of the national metrology institutes to the increasing European integration has brought PTB many opportunities, but also new responsibility. Also within Germany, the current importance of metrology and of PTB as a science-based service provider with a broad spectrum of offerings has grown and has meanwhile been excellently confirmed in two evaluations. This issue will conclude with an inventory-taking and with the vision for the next decades as it presents itself today. These show that the 125-year-old intention of Werner von Siemens still helps today to shape the future vigourously.

1872 – Schellbach Memorandum

The Schellbach Memorandum *"On the foundation of a museum for exact sciences"* of 30 July 1872 was named after the mathematician Karl-Heinrich Schellbach and is regarded as the first document aimed at establishing a national institution for precision metrology to improve the technical prerequisites for natural scientific research. The paper, which was directed at the crown prince (the later emperor Frederick III), bears the signatures of Hermann Helmholtz, Emil du Bois-Reymond and Wilhelm Foerster, among others. It was rejected by the Prussian Academy of Sciences.

1883 – Memorandum for a Prussian physical-mechanical institute

After lengthy political discussions, Helmuth von Moltke and the Prussian Minister of Education, Gustav von Gosler, appointed a new commission which – in a *"Memorandum concerning the justification of an institute for the experimental advancement of exact natural scientific research and precision technology (a physical-mechanical institute)"* of 16 June 1883 – called for an institute which was to carry out natural scientific and technical investigations in the fields of optics, electricity, mechanics, metallurgy, etc. and which was to serve – at the same time – as a testing and experimental station for physical instruments, materials and products. Members of this commission were, among others, Foerster, Helmholtz and Siemens, who had achieved that – contrary to the field of precision mechanics – "the focus must be more strongly on science".

1873 – Memorandum of Wilhelm Foerster

After the failure of the Schellbach Memorandum, Wilhelm Foerster submitted, on 27 October 1873, an almost identical memorandum to the head of the *"Prussian Land Triangulation"*. He shifted the focus of his justification from the general benefit for culture and the dissemination of exact sciences to practical applications such as, for example, surveying and mapping. General Field Marshal Helmuth von Moltke adopted Foerster's arguments in his *"Proposals for the elevation of scientific mechanics and instruments"* of 25 April 1874.

1884 – Memorandum for the establishment of an "Imperial Physical Technical Institute (PTR)"

In another memorandum of 20 March 1884, Werner von Siemens offered the German Empire *"a donation of half a million marks in estate or capital … for the establishment of a laboratory which should be dedicated to scientific fundamental investigations"*. Hermann von Helmholtz elaborated the "tasks of the first (i. e. the "scientific") division of the Imperial Physical Technical Institute", Wilhelm Foerster the "tasks of the second (i. e. of the "technical") division …".

1872

1884 – Werner von Siemens – A key personality for the PTR

Until 1838, Werner Siemens (1816–1892) studied at the *Berlin School of Artillery and Engineering.* He then became an internationally successful entrepreneur and inventor. With his company Siemens & Halske, he did pioneering work in the construction of telegraph circuits and the laying of overseas cables. Although Siemens always tried to make physical findings usable for society, he felt strongly attracted to "pure physics" and made some physical experiments of his own. He developed the dynamo and was the first to use electricity for public lighting in Berlin, as well as for the powering of locomotives, elevators and buses. In 1888, he was ennobled. Without his personal and financial commitment, the PTR would not have been founded.

1884 – Siemens formulates the tasks of the future PTR

In November 1884, Werner Siemens presented a detailed plan regarding the future tasks of the PTR. For the "Scientific Division", he planned: (1) the solution "of scientific fundamental determinations", including the repetition of older results with improved means; (2) the experimental determination of unsolved problems; (3) "experimental research work for the extension of our knowledge of nature." It was planned that the "Technical Division" should work in the following fields: (1) material testing and the determination of constants; (2) precision mechanics; (3) optics; (4) thermometry; (5) electrical engineering.

1887 – Foundation of the PTR

On 28 March 1887, the newly elected Imperial Diet approved a total of 700,432 marks for buildings, equipment and staff of the PTR. This date therefore stands for its foundation. On 1 October 1887, the "Physical Division" commenced working in the private laboratory of Johannes Pernet and on 17 October 1887, the "Technical Division" started in rooms of the Technical University of Charlottenburg.

1887 – The Kuratorium begins its work

The first "Kuratorium" of the PTR consisted of 24 representatives from government, science and industry. Among its duties were the examination of the annual report of the president, the rendering of consultancy with regard to the PTR's working programme and budget, and the approval of appointments.

1888 – "Photometry" as a field of work

Inspired by the *"Deutscher Verein der Gas- und Wasserfachmänner" (German Association for Gas and Water Experts)*, the PTR assumed the task of establishing an internationally accepted measurement standard of the greatest possible accuracy and of developing much more efficient visual photometers for the determination of the luminous intensity of lamps – among other things for public lighting.

1889 – Lummer-Brodhun cube

In 1889, Otto Lummer and Eugen Brodhun developed a visual photometer at the PTR which was based on the so-called "Lummer-Brodhun cube". With this photometer, the equivalence of the luminous intensity of two light sources could be adjusted very precisely with the eye and allowed – together with defined attenuation methods and a standard – a luminous intensity scale to be developed.

1890 – Feussner compensator

Karl Feussner invented the d. c. voltage compensating device which allowed currents to be measured with high precision by traceability to voltage and resistance. In addition, the Feussner compensator could also be used for voltage and resistance measurements.

1890 – Hefner lamp ("Hefner candle")

According to investigations of the PTR, the "Hefner candle", an amyl acetate lamp, represented a primary standard for the unit of luminous intensity with always identical properties and an uncertainty of 1.5 %. From 1896 to 1941, this lamp was used as a state-approved standard in Germany, Austria and in Scandinavia.

1891

1888 – Hermann von Helmholtz becomes the first president of the PTR

Hermann Helmholtz (1821–1894) studied medicine in Berlin and, in 1842, obtained a doctoral degree in anatomy. After physiological teaching activities in Königsberg, Bonn and Heidelberg, he became – in 1870 – the successor of Gustav Magnus as a full professor of physics in Berlin. He was one of the most creative and productive physiologists and physicists of the 19th century. He gained fame by his epoch-making work concerning the sense of sight and the sense of hearing and the invention of the ophthalmoscope and acoustic resonators. This was continued later by his paper regarding the "conservation of force", that means the conservation of energy. In 1883, he was ennobled. Together with Werner von Siemens and others, he campaigned personally for the foundation of the PTR and became its first president from 1888 to 1894.

1891 – The "Science of Colours" by Helmholtz

Even as the president of the PTR, Hermann von Helmholtz worked scientifically on his three-component science of colours with the laws of the additive and subtractive colour mixture. His three variables – tonality, saturation and brightness for the characterization of colour – are still used today.

Helmholtz and the Founding Years

Helmut Rechenberg

In the 19th century, the systematic industrialization in and outside of Europe began, for which the steam engine and the telegraph became characteristic symbols. At the same time, the classical natural sciences of physics, chemistry and atomology were completed, a systematic system of basic units – the Gauss-Weber CGS (centimetre gram second) system including the electrical and magnetic quantities – was introduced and used for industrial as well as for other socio-political and also military interests.

Soon after the foundation of the new German Empire (in 1871), Karl-Heinrich Schellbach, professor of mathematics at the Berlin War Academy, who was advised by outstanding colleagues from the natural sciences (namely Emil du Bois-Reymond, Wilhelm Foerster, Hermann Helmholtz and Carl Adolf Paalzow), sent a memorandum to his former pupil, Crown Prince Friedrich Wilhelm (the later Emperor Frederick III) on 30 July 1872. Initially, this "Schellbach Memorandum" stipulated the setting up of a collection of such instruments which had attained *"a scientific importance"*, including machine tools *"serving for the manufacture of precision devices"*. The *"main purposes of this richly equipped collection which should be accessible to everyone"* should be, amongst other things, *"(1) to inform scholars and laymen of the point of view and progress of science by presenting the devices and their essential functions; (2) to provide the mechanics with samples for their work..."*; and *"(3) to hand over the devices and machine tools to persons who offer the necessary guarantees."* Expenses of 20,000 Reichstaler would be required. The institute's administration and its acquisition plan ought to be controlled by an *"advisory board, a so-called 'Kuratorium', consisting of representatives of the exact sciences and their teachings"*. Crown Prince Friedrich Wilhelm passed this memorandum on to the responsible Prussian minister in September 1872, who had it checked by the Prussian Academy of Sciences. However, it was rejected by the latter. Although thereupon, Wilhelm Foerster addressed himself to the chief of the German general staff, Helmuth von Moltke, and won him over to the project, the Prussian *Haus der Abgeordneten (House of Representatives)* definitely refused it.

In the summer of 1883 – after an interruption of ten years – Hermann Helmholtz and Werner Siemens dealt again with this matter and wrote the *"Memorandum concerning the foundation of an institute for the experimental promotion of the exact sciences and for precision technology (Physical-Mechanical Institute)"*. For that purpose, Siemens also wanted to donate a landed property close to the *Technische Hochschule Charlottenburg* and pay the costs for the *"construction of the required buildings"* from the heritage of his brother William. The acceptance of this donation was finally approved by the *Imperial Diet ("Reichstag")* in March 1887 – against the objection of the state of Bavaria. Renowned personalities of science like the optician Ernst Abbe and the medical scientist Rudolf Virchow advocated it.

Twenty-four experts from universities and industry were appointed to the *Kuratorium*. The actual initiators of the PTR, Helmholtz and Siemens, developed the structure of the new institute: a "Physical Division" and a "Technical Division". Helmholtz, who was made a hereditary peer in 1883, became its first president in 1888 and was responsible for the further development of the PTR.

Hermann Ludwig Ferdinand Helmholtz, who was born in Potsdam in 1821, was one of the most influential natural scientists of his time. His colleague James Clerk Maxwell – a physicist – even called him an "intellectual giant". Following his studies at the Medical-Surgical Institute in Berlin,

Picture left page: Helmholtz memorial by E. Herter, 1899, in the Court of Honour of the *Humboldt-Universität zu Berlin*

Picture right page: Preliminary drawing of the PTR in Charlottenburg, created between 1884 and 1887 he served as surgeon and army doctor at the Berlin Charité and in Potsdam. In 1842, he received his doctoral degree – together with Emil du Bois-Reymond and Rudolf Virchow – from the great physiologist Johannes Müller at the University of Berlin, and – like the engineer Werner Siemens – joined the just founded "Berlin Physical Society" in 1845. There, he presented the general formulation of the law of the conservation of energy in his lecture "On the Conservation of Force" on 25 June 1847. After a professorship of anatomy at the *Berliner Akademie* he was appointed as associate professor of physiology at the University of Königsberg in East Prussia and was promoted there as full professor as early as 1850 and as dean of the Faculty of Medicine in 1854. Supported by his first wife Olga von Velten, he undertook pioneering work on the propagation of signals along the nerve fibres. Moreover, he invented the ophthalmoscope and the ophthalmometer for the measurement of the corneal curvature. In 1855, he accepted a professorship of physiology and anatomy at the University of Bonn; however, he moved on to Heidelberg already in 1858. During this period he wrote the "Handbook of Physiological Optics" and the "Theory of the Sensations of Tone" including physical and anatomical studies on the human ear and hearing. Olga Helmholtz died in Heidelberg at the end of 1859. Some months later, Helmholtz married his second wife, Anna von Mohl.

During his journeys to Great Britain beginning in the summer of 1853, he became acquainted with renowned physicists, notably the Englishman Michael Faraday (*"the currently first physicist of Europe"*). In 1855, he met the Scotsman William Thomson in Germany, whom he visited quite frequently later on. In 1871, after the death of Gustav Magnus, he became his successor as full professor of physics at the University of Berlin, after he had introduced himself as physicist by means of important works on hydrodynamics and electrodynamics. Together with his friend du Bois-Reymond, he established and equipped two neighbouring institutes for physics and physiology. Helmholtz now began a successful career as physicist in cooperation with visitors like Ludwig Boltzmann and Albert Abraham Michelson, and pupils like Heinrich Hertz.

His promoter, Siemens, was occasionally reproached for having tailored the planned PTR completely to his friend Hermann von Helmholtz. Thus, already in May 1889, the Helmholtz family could move into the residential house, which was one of the buildings constructed for the PTR on the Siemens site. It soon became the centre of an illustrious society, ranging from the crown prince and crown princess to leading colleagues of the PTR. Among the latter, special mention should be made of Otto Lummer and Friedrich Kurlbaum

who were heads of the "Optical Laboratory" of the PTR, as well as of their assistant and the pupil of Helmholtz, Wilhelm (Willy) Wien.

At the time of Helmholtz, the PTR had 65 employees, among them more than a dozen physicists; and it had a budget of 263 000 Reichsmarks. The president drew wages of 24 000 Reichsmarks, for which, however, the state committed him to give one- to three-hour lectures on theoretical physics at the University. In his memorial speech for his old friend at the *Berliner Akademie* in July 1895, Emil du Bois-Reymond commented on the high salary classification with the phrase *"that the president of such a comprehensive, multiple-structured institute with 50 civil servants, which partly had the character of an educational institution and partly that of a factory, had to cope with an enormous amount of administrative work which – due to its newness and strangeness – burdened him all the more."*

In 1897, his successor Friedrich Kohlrausch could finally also put into operation the other planned buildings of the PTR. For the "Physical Division", in addition to the already existing residential home of the president, the Observatory as well as an administrative building and the "magnetic" house. For the "Technical Division": the main building, a laboratory building, the machine house, a boiler house, the little ventilator house and the residence of the director.

As Hermann von Helmholtz died in 1894 – shortly after his 73rd birthday, he did not live to see the great scientific successes of his institute for which he had set the foundations. Following his mathematical studies at the Universities of Göttingen and Berlin, the East Prussian Willy Wien joined the laboratory of Hermann von Helmholtz at the University of Berlin in the winter semester 1883/84, to which he returned after having spent one semester in Heidelberg. There, he received his doctoral degree for a work on optics in 1886. In 1890, he joined the PTR and turned to the field of thermal radiation by means of thermodynamic and electrodynamic methods. In 1895 he suggested, together with Otto Lummer, that a blackbody radiator should be realized in the form of a cavity which is heated to a constant temperature. One year later, the measurements of Lummer together with the Helmholtz pupils Ernst Pringsheim, Ferdinand Kurlbaum and Heinrich Rubens ultimately led to "Wien's law of radiation". This formula could be derived by Max Planck in 1899 who was a full professor for theoretical physics at the University of Berlin. Deviations which were subsequently discovered by Rubens and Kurlbaum in measurements at high temperatures and great wavelengths then led Planck to an improvement of Wien's law by means of introducing radiation quanta. His lecture on this subject, held on 14 December 1900 at the meeting of the *Deutsche Physikalische Gesellschaft*, is commonly considered as the dawning of a new era of physics. ■

1891 – The Observatory

The Observatory, located in the middle of the grounds of the PTR, was custom-made for the precision measurements carried out by the "Physical" Division. Erected on a 2-metre thick concrete base plate, with reinforced, extremely solid arches, it offered the best preconditions to suppress mechanical vibrations. An insulating basement vault, an optimal routeing of the air flow, and the arrangement of the most important measurement laboratories within the windowless core of the building ensured excellent temperature stability. Both the suppression of vibrations and temperature stability form an indispensable precondition for precision.

1892 – Feussner and Lindeck develop "Manganin"

The material "Manganin" developed by Karl Feussner and Stephan Lindeck in cooperation with the *Isabellenhütte* in Dillenburg combines high specific resistivity and a low temperature coefficient with an excellent long-term stability as well as a low thermoelectric potential compared to copper. Manganin is the material that is most frequently used in the fabrication of resistors.

1892 – The Loewenherz thread becomes standard

The precision-engineering thread presented by Leopold Loewenherz back in 1889 was originally a V-thread. In 1892, it became recognized as a standard thread in its flattened variant and was used in the optical industry as the "Loewenherz thread" for 40 years before being replaced by the metric thread DIN 13.

1893 – Wien's displacement law

Based on thermodynamic observations, Wilhelm Wien succeeded in describing the thermal radiation of a black body with the displacement law he formulated. This law exactly describes the displacement of the maximum of the radiation emission of a black body with increasing temperature towards shorter wavelengths.

1895 – Radiometry

In 1895, radiometry, as the science of the quantitative measurement of electromagnetic radiation and its application, became an important field of work of the PTR as it enables, for example, exact measurements of the thermal radiation of black bodies and also the physiological evaluation of visible light
(see: "Photometry" as a field of work, page 7).

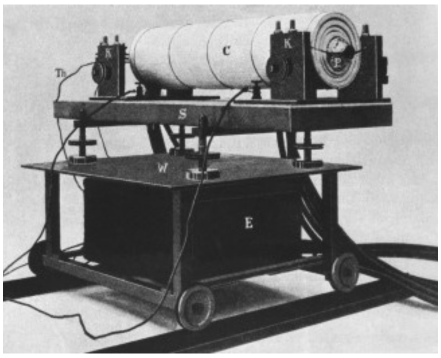
1895 – Kohlrausch writes his "Textbook of Practical Physics"

Friedrich Kohlrausch published his *"Lehrbuch der praktischen Physik" ("Textbook of Practical Physics")* – which has, to date, been edited 24 times – at the B. G. Teubner publishing house. It was meant as an introduction to practical experimental work for beginners and as an aid for experts in solving practical problems in research.

1891

1891 – Wilhelm Foerster becomes president of the CIPM

Wilhelm Foerster (1832–1921) studied mathematics, physics, art history and – later – astronomy in Berlin and Bonn. From 1865 to 1904, he was the director of the Berlin Observatory *("Berliner Sternwarte")*. In 1869, he became the director of the newly founded *Normal-Eichungskommission (Standards Verification Commission)* of the North German Confederation (and – later – of the *German Empire*). This commission was strongly shaped by him. But Wilhelm Foerster also proved to be a successful negotiator and organizer. Amongst other things, he contributed decisively to the formation of the Metre Convention in Paris in 1875 and was head of the Comité International des Poids et Mesures (CIPM) from 1891 to 1920. Furthermore, from 1873 on, he was considerably involved in all preliminary discussions concerning the foundation of the PTR. In this context, he initiated various memoranda and was a member of the PTR's *Kuratorium (Advisory Board)* from 1887 to 1921.



1895 – Lummer and Wien develop the first cavity radiators

Based on an idea of Gustav Kirchhoff (1860), Otto Lummer and Willy Wien developed the first cavity radiators for the practical generation of the thermal radiation of black bodies.

1896 – Schönrock improves sugar analysis

In order to support industry, the basis of sugar analytics was laid at the PTR in 1896 with the aid of polarimetry. Otto Schönrock developed new saccharimeters to measure the optical activity of sugar solutions and investigated the properties of standard sugar solutions and quartz plate standards.

1896 – Wien's radiation law

In 1896, Wilhelm Wien formulated a radiation law which was thought for a few years to exactly describe the thermal radiation of a black body – until precision measurements performed by Otto Lummer and Ernst Pringsheim (1899) as well as by Ferdinand Kurlbaum and Heinrich Rubens (1900) demonstrated considerable deviations at higher temperatures and longer wavelengths.

1897 – The Central Building (later: Werner von Siemens Building)

For the tasks of the second division of the PTR (i. e. the "Technical" Division), the four-storey, U-shaped central building was erected opposite the Observatory.

1898 – Orlich builds self-inductance standards

In 1898, Ernst Orlich manufactured the first self-inductance standards in accordance with Max Wien's method and developed exhaustive calculations for inductance and capacitance standards which were published at the Vieweg publishing house. These activities were later continued by Erich Giebe and Gustav Zickner.

1899 – Deviations from Wien's radiation law

In 1899, Otto Lummer and Ernst Pringsheim measured deviations of the emitted thermal radiation from Wien's radiation law on an electrically heated cavity radiator at temperatures of up to 1600 °C and wavelengths of up to 6 µm. When the measurements were extended to 18 µm, the deviations increased.

1900 – Gumlich investigates transformer sheets

In 1900, Ernst Gumlich discovered that iron containing silicon exhibits increased electric resistivity and, thus, lower eddy current losses. This discovery was picked up in the mechanical engineering of electrical components. Gumlich's discovery triggered off one of the most important technical and economic impulses which ever emanated from the PTR.

1900

1895 – Friedrich Kohlrausch becomes president of the PTR

Friedrich Kohlrausch (1840–1910) studied physics in Erlangen and Göttingen. From 1870 on, he was a full professor in Zurich, Darmstadt, Würzburg and Strasbourg successively. Kohlrausch is considered one of the most talented metrologists of the 19th century and as one of the co-founders of physical chemistry. He was the author of the first textbook on experimental physics published in 1870 as the *"Leitfaden der Praktischen Physik" ("Guide to Practical Physics")* which he extended to make it a textbook for generations to come. He was a member of the PTR's *Kuratorium* from the very beginning until 1910 and president of the PTR from 1895 to 1905.

1898 – Law concerning the electrical units of measurement *("Gesetz betreffend die elektrischen Maßeinheiten")*

In 1898, the PTR was assigned its first legally relevant task through the *Gesetz betreffend die elektrischen Einheiten* signed by Emperor Wilhelm II on 1 June 1898. This task was to realize and maintain the electric units defined in this law and to test measuring instruments for electrical quantities.

The "Black Body" and the Quantization of the World

Jörg Hollandt

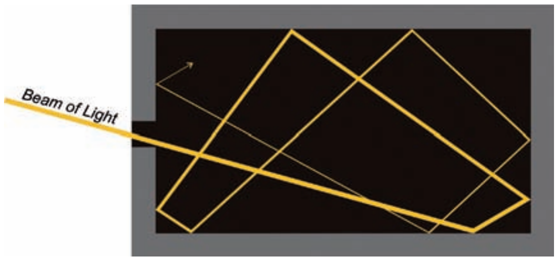
At a temperature above the absolute zero point, each body emits electromagnetic radiation which is referred to as "thermal radiation". Already in 1860, Gustav Kirchhoff realized that for a body which completely absorbs all incident radiation (absorptivity $\alpha = 1$), the spectrum of the emitted thermal radiation is independent of the form and the material of the body, and is only a function of the wavelength and of the temperature [1]. Since the time of Kirchhoff, such a body has been called a "black body".

On the basis of the second law of thermodynamics, Kirchhoff concluded that – in thermal equilibrium – for the same temperature, wavelength and direction, the directional spectral absorptivity is equal to the directional spectral emissivity. The spectral emissivity describes a body's capability to emit thermal radiation. For a black body, the spectral emissivity is thus equal to one for all wavelengths, and no body of the same temperature can emit more thermal radiation than a black body.

After this important discovery of Gustav Kirchhoff, the search for an analytical description of the thermal radiation spectrum of the black body became the most prominent challenge of theoretical physics towards the end of the 19^{th} century.

Soon after the founding of the *Physikalisch-Technische Reichsanstalt (Imperial Physical Technical Institute* – PTR) in 1887, the measurement of the radiation of black bodies became an important task of the laboratory for optics; it was conducted by the scientists Ferdinand Kurlbaum, Otto Lummer, Werner Pringsheim, Heinrich Rubens and Wilhelm Wien.

In 1892, Kurlbaum and Lummer developed the electrical substitution radiometer for the quantitative measurement of electromagnetic radiation, which was an absolute prerequisite for the measurement of thermal radiation. Also for the practical generation of the thermal radiation of a black body, the PTR physicists Wien and Lummer broke new ground by proposing isothermal cavities as radiation sources in 1895. Thus, they acted on an idea which Kirchhoff had already put forward. According to Kirchhoff, the thermal radiation inside an isothermal cavity should exactly correspond to the radiation of a black body. To observe the radiation, the cavity has to be provided with a small aperture. As long as the aperture is very small compared to the surface of the cavity, a light beam falling into the cavity can pass through many reflections on the walls of the cavity and will finally be completely absorbed. Thus, the only radiation that leaves the cavity is the thermal radiation of a black body that has been generated in the cavity.



Picture on this page: "Complete" absorption of a light beam which falls into a black body

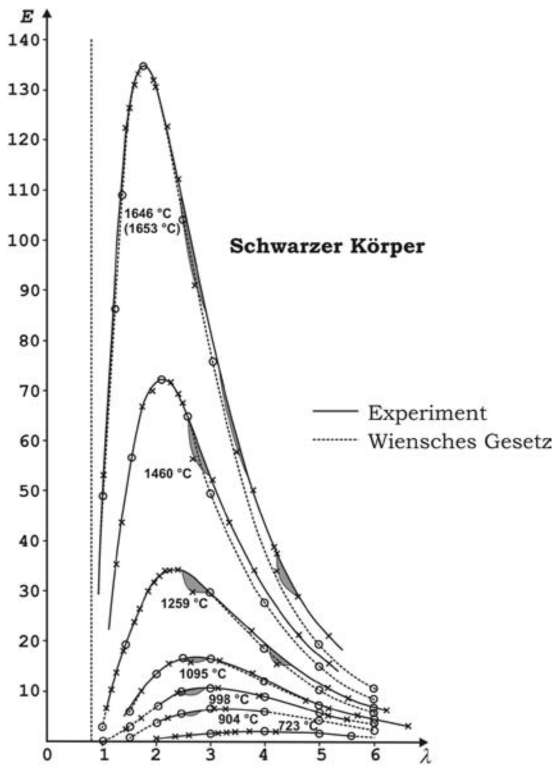
Figure right page, left column: Spectrum of the thermal radiation emitted by a black body, measured by Lummer and Pringsheim in 1900 and compared to Wien's radiation law

Picture right page, right column: High-temperature cavity radiator of PTB which can reach temperatures of 3000 °C. The temperature is measured optically by means of absolutely calibrated radiation detectors.

Initial investigations on these cavity radiators led Wien to the formulation of a radiation law in 1896 which was named after him and which led to the belief for a few years that it would describe thermal radiation correctly [2]. In the following three years, Lummer and Kurlbaum developed an electrically heated cavity radiator which could generate thermal radiation up to 1600 °C. Exact measurements carried out by Lummer and Pringsheim with this radiator showed significant deviations from Wien's radiation law at higher temperatures and greater wavelengths [3]. The broken line in their diagram was calculated according to Wien's radiation law. The continuous line represents the result of the measurements in the spectral range of 1 µm to 6 µm, which increasingly deviate from Wien's radiation law at high temperatures and increasing wavelength.

In 1900, Rubens and Kurlbaum used the *"Reststrahlenmethode" (residual ray method)* in order to be able to demonstrate unambiguously at even greater wavelengths that with rising temperature, deviations of the measurements from Wien's radiation law became more and more obvious [4]. Rubens reported this result personally to Max Planck who was dealing with the theory of black bodies at the *Friedrich-Wilhelms-Universität (Friedrich Wilhelms University)* in Berlin. On the very same day, 7 October 1900, Planck empirically discovered a formulation of the radiation law for the black body which agreed with all measurements carried out by the PTR. On 19 October, he presented this result at a meeting of the *Deutsche Physikalische Gesellschaft (German Physical Society)* following a lecture held by Kurlbaum [5].

In the following two months, Planck succeeded in a theoretical deduction of his equation. For this purpose, he transferred the concept of the harmonic oscillator (which had been introduced by Heinrich Hertz in 1889 to describe the emission and absorption of electromagnetic radiation) to the thermal radiation of the black body. In an "act



of desperation", Planck only allowed certain (discrete) states of energy. On 14 December 1900, he presented his deduction of the radiation law at the meeting of the *Deutsche Physikalische Gesellschaft* in Berlin [6]. Today, this meeting is regarded as the "hour of birth of quantum mechanics".

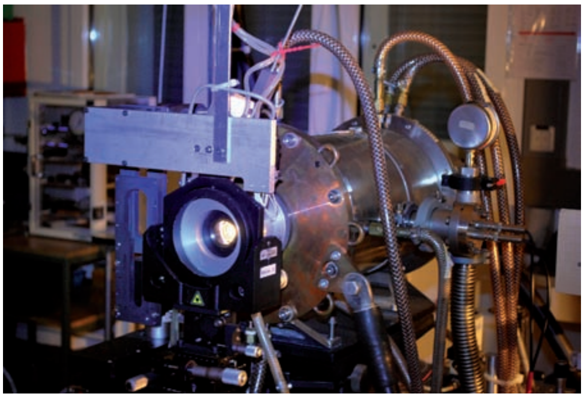
Besides the dependence of the spectral radiance on temperature and wavelength, the thus derived Planck's radiation law named after him contains also three fundamental constants: the speed of light *c*, the Boltzmann constant *k* and Planck's constant *h*.

$$L_\lambda = \frac{2hc^2}{\lambda^5} \cdot \frac{1}{\exp\left(\frac{hc}{k\lambda T}\right) - 1}$$

In this formulation of Planck's radiation law, L_λ describes the spectral radiance of the black body in vacuum. The spectral radiance with the unit W nm^{-1} m^{-2} sr^{-1} is the emitted spectral radiant power normalized to the surface of the radiating body and the solid angle to which the radiation is emitted.

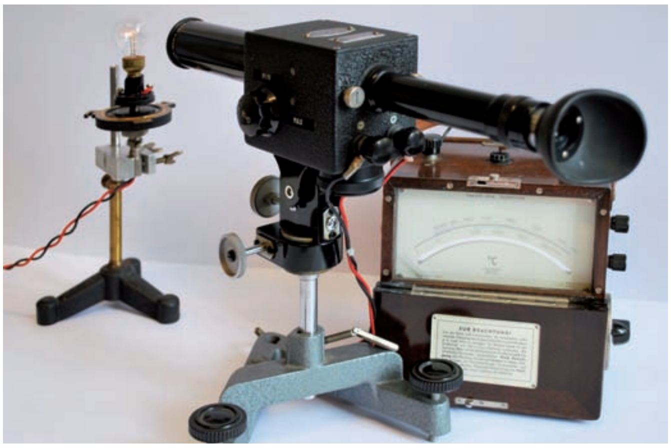
After a comprehensive theoretical understanding of thermal radiation had been achieved, the PTR developed the respective temperature measurement, which today is referred to as "radiation thermometry", into a precise method of the non-contact temperature measurement in science and technology. For nearly one century, the high-temperature cavity radiator introduced by Lummer and Kurlbaum was the only primary radiation standard for the realization and dissemination of temperature and radiation. It was not until the 1980s that a second primary radiation standard – the electron storage ring – could be developed.

Today, the cavity radiator is still used for the realization and dissemination of the high-temperature scale as well as of radiometric and photometric quantities from the ultraviolet up to the infrared spectral range. Only recently, a cavity radiator has been developed at PTB which even permits radiation measurements to be carried out in the extremely long-wave spectral range of THz radiation (30 µm up to 1500 µm). At PTB, blackbody radiation can nowadays be generated by means of precision cavity radiators at any temperature in a range from −170 °C up to 3000 °C. [7]. For the calibration of radiation thermometers, standard measurement uncertainties of 70 mK are achieved at the freezing point of silver (approx. 962 °C) and 700 mK at 3000 °C, and thus the measurement uncertainty requirements are met which are placed on radiation thermometry as a quick and non-contact method of temperature measurement for modern production monitoring and control.



Today, temperature measurements of the Earth's surface from outer space and of the Earth's atmosphere with a very high resolution over long periods of time and over great areas represent a new challenge for temperature measurement on the basis of the black body. They are intended for the precise monitoring of possible climate changes and provide important input data for climate model calculations. But not only for remote sensing of the Earth, but also for industrial process engineering, imaging temperature measurement is becoming more and more important. The bolometer, which was still used by Kurlbaum as an individual detector, is now manufactured lithographically as a sensor array with typically 12,000 to 310,000 single bolometers with a sensor size of 25 µm × 25 µm, and is integrated as a key component in thermographic cameras which are becoming less and less expensive. Measuring facilities are developed and operated at PTB which allow the instrumentations of remote sensing of the Earth and imaging temperature measurement systems to be calibrated with reference to the cavity radiation under application-oriented conditions and thus the measurements performed with a small measurement uncertainty to be traced back to the International Temperature Scale. Thus, the Physikalisch-Technische Bundesanstalt stands for 125 years of continuous work on and with the radiation of the black body. ■

[1] *G. Kirchhoff:* Ann. Phys. Chem. **109**, (1860), 275–301
[2] *W. Wien:* Ann. Phys. **294**, (1896) 662–669
[3] *O. Lummer, E. Pringsheim:* VhDPG 2, (1900), 163–180
[4] *H. Rubens, F. Kurlbaum:* Ann. Phys. **309** (1901), (IV,4), 649–666
[5] *M. Planck:* VhDPG 2, (1900), 202–204
[6] *M. Planck:* VhDPG 2, (1900), 237–245
[7] *J. Hollandt, R. Friedrich, B. Gutschwager, D. R. Taubert, J. Hartmann:* High Temperatures – High Pressures **35/36**, (2003/2004), 379–415



1901 – Holborn and Kurlbaum develop the disappearing filament pyrometer

In 1901, Ludwig Holborn and Ferdinand Kurlbaum developed the disappearing filament pyrometer as an optical radiation thermometer for the exact, non-contact temperature measurement of high temperatures. This principle is still used in modern measuring instruments.

1900 – Planck's radiation law

In October 1900, Max Planck found an exact description of blackbody radiation on the basis of the measurement results obtained by the PTR. By December 1900, he had succeeded in strictly deriving the empirically compiled radiation law, assuming that electromagnetic radiation is emitted and absorbed in discrete energy quanta. This was the birth of quantum theory.

1902 – Lummer-Gehrcke plate

With the Lummer-Gehrcke plate, Otto Lummer and Ernst Gehrcke developed at the PTR, in 1902, an interferometer of highest resolution for the optical spectral range. Until the highest reflecting mirrors reached technological maturity, the Lummer-Gehrcke plate remained, for many decades, one of the interferometric instruments with the highest resolution.

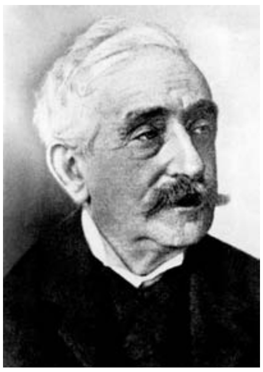
1903 – Hagen and Rubens measure reflection and conductivity

In 1903, Ernst Hagen and Heinrich Rubens discovered the relation between the conductivity of a metal and its reflectivity in the infrared spectral range where high electric conductivity corresponds to high reflectivity. The Hagen-Rubens relation was an early indicator of the presence of free electrons in metals.

1906 – Gehrcke and Reichenheim discover anode rays

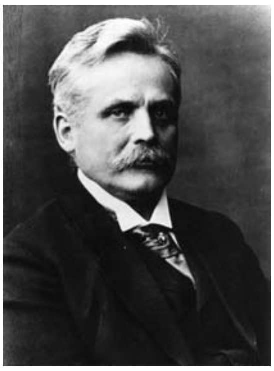
In 1906, Ernst Gehrcke and Otto Reichenheim discovered anode rays as corpuscular rays (positive ions) emitted by the anode of a gas-filled discharge tube. Exhaustive investigations of the anode rays, their speed, the charge-to-mass ratio as well as spectroscopic measurements followed.

1900



1905 – Emil Warburg becomes president of the PTR

Emil Warburg (1846–1931) first studied chemistry in Heidelberg, but later switched to physics at the University of Berlin. After working as a professor in Strasbourg and Freiburg, he was offered a chair at the University of Berlin in 1894. In 1897, he became director of the *Physikalische Gesellschaft zu Berlin* and then the first president of the *Deutsche Physikalische Gesellschaft (German Physical Society – DPG)*. In 1905, he succeeded Friedrich Kohlrausch as president of the PTR and opened it up for new approaches to physics (relativity theory, quantum theory). He established laboratories for modern fields of research such as, e.g., low-temperature physics, radioactivity, high-power current and high voltage. In 1914, he undertook a restructuring of the institute according to specific fields of work. In 1922, he retired at the age of 76 and from then on lived in Bayreuth.



1911 – Nobel Prize in physics awarded to Willy Wien

Wilhelm ("Willy") Wien (1864–1928) studied physics in Göttingen and Berlin. After having already worked in the laboratories of Hermann von Helmholtz, he became his assistant at the PTR in 1889. There, he mainly dealt with the laws of thermal radiation. Together with his colleagues, he

1911 – First Solvay Conference

The Solvay Conferences were intended to promote scientific exchanges between the most important physicists at the highest level. On the occasion of the first of these conferences, which was dedicated to the topic "Radiation and Quantum Theories", the PTR was represented by its president, Emil Warburg, as well as by Heinrich Rubens.

1906 – Warburg confirms Planck's radiation law

In 1906, Emil Warburg and his staff improved the radiation measurement on black bodies and, thus, determined the fundamental constants in Planck's radiation law more precisely. Their aim was also to establish an international light standard based on the black body.

1906 – The beginnings of photochemistry

Emil Warburg's work on the transformation of energy in gas reactions experimentally confirmed the quantum theory and the fundamental work carried out by Albert Einstein and Johannes Stark. According to Einstein, this work established photochemistry in a quantitative manner.

1911 – The discovery of superconductivity

After Heike Kamerlingh Onnes, director of the low-temperature laboratory of the University of Leiden, had succeeded in liquefying helium for the first time in 1908, he discovered, together with his colleague Gilles Holst, that the electrical resistivity of mercury decreases abruptly down to an indeterminably small value at temperatures below 4.2 K. This new state of matter was given the name of "superconductivity". Superconducting circuits have meanwhile become indispensable for electric and magnetic high-precision measurement devices.

1913 – Geiger-Müller counter

In 1913, Hans Geiger developed the first gas-filled counting tube to detect single radiation quanta. By means of the principle of gas amplification by collision ionization, the single electrons generated by the primary ionization processes can be detected. From this needle counter, the Geiger-Müller tube – a measuring instrument for radioactivity research established worldwide until today – was developed in 1928 in collaboration with Walter Müller and named after its two inventors.

1913

succeeded in realizing a nearly perfect black body. He developed the displacement law and the radiation law (both of them named after him – *Wien's displacement law* and *Wien's radiation law)* for which, in 1911, he was awarded the Nobel Prize in physics. In 1896, he went to Aachen, and in 1899, he became a professor in Gießen. One year later, he became Wilhelm Conrad Röntgen's successor in Würzburg and then succeeded him in Munich in 1919. in München.

1913 – Hans Geiger sets up the Radioactivity Laboratory

Johannes Wilhelm ("Hans") Geiger (1882–1945) studied physics in Erlangen and Munich. After that, he went to Manchester and became an assistant of Ernest Rutherford. In 1912, he joined the PTR's staff and set up a laboratory for radioactivity; with two other employees, he began investigating sources of radium, mesothorium and radiothorium for medical purposes. One year later, he became the head of this growing working group (which was part of the Optical Laboratory). Within a short period of time, he developed his department to a world-class scientific centre for radioactivity and recruited competent colleagues such as Walther Meissner, Walther Bothe and James Chadwick. In 1925, he went to Kiel as a professor, in 1929 to Tübingen and in 1936 to the Technical University of Berlin. During World War II, he initially participated in the uranium project.

The "Kuratorium", PTB's Advisory Board

Robert Wynands

From the very beginning (to be more exact: from 6 August 1887), the *Physikalisch-Technische Reichsanstalt (Imperial Physical Technical Institute* – PTR) had a management tool which, from our present-day perspective, was really quite modern: the *"Kuratorium" (Advisory Board)*. Now as then it fulfils – on the one hand – the role of a scientific advisory board and represents – on the other hand – the interests of PTB's customers from the scientific, economic and social sectors. Its task is/was to advise both the PTR/PTB itself as well as its supervisory ministry (in the past: *the Reichsamt des Inneren – Imperial Office of the Interior,* today: the *Bundesministerium für Wirtschaft und Technologie – Federal Ministry of Economics and Technology)* on all issues concerning this institute. Especially in important strategic decisions, the *Kuratorium* can provide important assistance and advice thanks to its wide-ranging expertise.

In the PTR, the *Kuratorium* assumed tasks which it no longer has in PTB today, namely that of proposing the PTR's budget for the coming year as well as of approving staff appointments and the visits of guest scientists. But scientific discussions did not come too short either. In the proceedings of the *Kuratoriumssitzung (Advisory Board Meeting)* of 1926 there is, for example, a passage in which – in a discussion about the PTR's activity report – one of the members of the *Kuratorium*, Albert Einstein, says on the subject of superconductivity: *"What is of particular interest is the question as to whether the contact point between two superconductors also becomes superconducting."* As far as we know, this question was not followed up at the time, but was taken up again only in the 1960s. Under the name "Josephson junction", the contact point of two superconductors divided by a thin, non-superconducting insulating layer became famous and – among other things – serves today for the practical realization of the volt (the unit of electric potential difference) with a relative uncertainty of less than 10^{-10}.

Table:
Nobel Prize winners in the Kuratorium of the PTR/PTB.

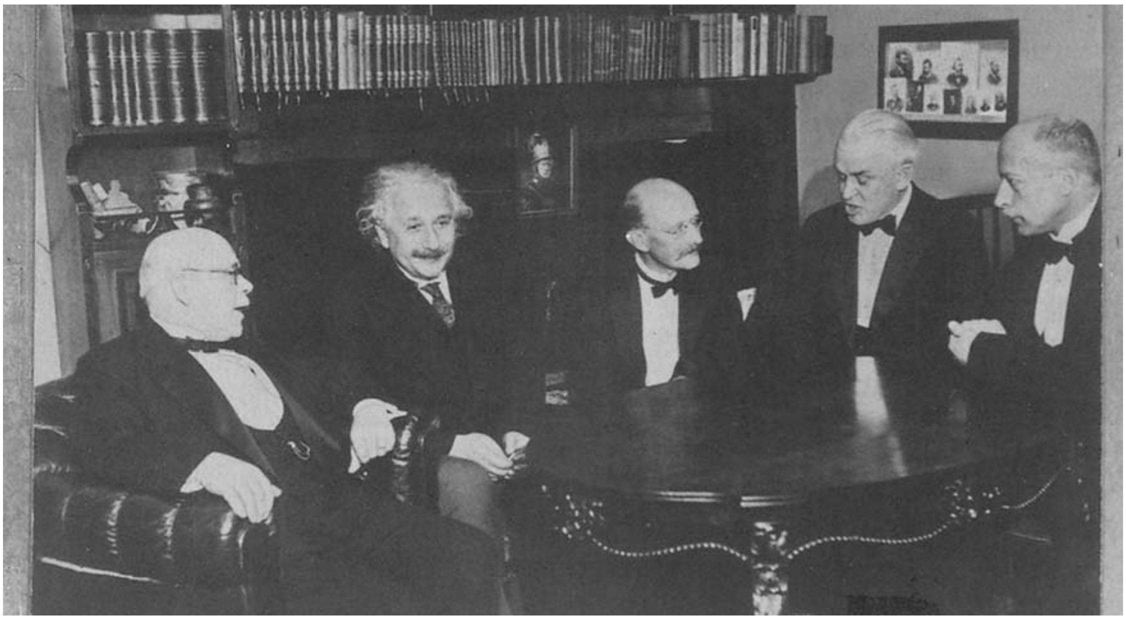
Member	Nobel Prize	in the Kuratorium from – to
Wilhelm Conrad Röntgen	Physics 1901	1897 – 1920
Philipp Lenard	Physics 1905	1926 – 1929
Wilhelm Wien	Physics 1911	1912 – 1928
Max von Laue	Physics 1914	1949 – 1960
Max Planck	Physics 1918	1908 – 1935
Fritz Haber	Chemistry 1918	1920 – 1935
Walther Nernst	Chemistry 1920	1895 – 1935
Albert Einstein	Physics 1921	1916 – 1933
James Franck	Physics 1925	1928 – 1935
Gustav Hertz	Physics 1925	1930 – 1935
Walther Bothe	Physics 1954	1953 – 1957
Klaus von Klitzing	Physics 1985	1989 –
Theodor W. Hänsch	Physics 2005	1999 –

The list of the members of the Kuratorium reads like a "who's who" of science and technology: in the first twenty years alone, scientists such as Wilhelm Foerster, Hans Heinrich Landolt, Rudolf Clausius, Friedrich Kohlrausch, Ernst Abbe, August Kundt, Georg Quincke, Emil Warburg and Karl Schwarzschild worked on this board. To date, a total of thirteen Nobel Prize winners have been members of the Kuratorium of the PTR/PTB – a sign of the high significance which both sides attribute to this type of advice.

The last Kuratorium meeting of the old PTR took place in 1933. At the beginning of 1935, the Kuratorium was disbanded at the instigation of the then President of the PTR, Johannes

Picture below:
Meeting of Nobel Prize winners in Berlin in 1923: Nernst, Einstein, Planck, Millikan, von Laue. Apart from Millikan, all of them were closely connected to the PTR for many years, for instance as members of the *Kuratorium*.

Picture right page:
PTB's *Kuratorium* in 2011 in front of the Vieweg Building



Stark, and its tasks were transferred to the President in accordance with the National Socialists’ *“Führer”* principle. After the Second World War, at the end of the 1940s, the institute was re-established under the name *“Physikalisch-Technische Anstalt”* (PTA). This institute had a *Kuratorium* again right from the start. People with illustrious names belonged the board once more, also including Max von Laue, who had been personally very engaged in re-founding the institute and had had close ties to the old PTR for many years as a “Theory Advisor”.

Today, PTB’s Kuratorium consists of approx. 25 outstanding individuals with roughly equal numbers from science and industry. The esteem and importance attached to PTB’s work also becomes evident by the fact that German industry is currently being represented at an equally

high level to science through the chairperson of Volkswagen AG as well as through other representatives from the executive level of large and medium-sized enterprises. Science is represented, for example, with two Nobel Prize winners and the president of the *Helmholtz-Gemeinschaft Deutscher Forschungszentren (Helmholtz Association)*.

The Kuratorium meets annually at a two-day meeting at PTB in Braunschweig as well as in Berlin, in order to gain a clear picture of PTB’s work through laboratory visits, a scientific colloquium as well as individual discussions with the staff of the divisions. Besides this, the Kuratorium receives the report of PTB’s president about the past year and discusses it. During this meeting and in various individual meetings over the year, the Kuratorium provides important impetus for the further orientation of PTB to the interests of science and the economy in Germany. This applies, in particular, to the planning of large-scale investments in construction or major investments made in equipment such as the Willy Wien Laboratory at Berlin Adlershof with the Metrology Light Source, a synchrotron radiation source specially tailored to the needs of metrology – in particular, radiometry.

The members of PTB’s Kuratorium are appointed for a five-year period. Re-appointments are possible. In contrast to the early years, there are no *de-facto* quotas according to specialist areas today, although care is, of course, taken to cover the whole spectrum of PTB’s scope and customers when new members are appointed. To identify possible new members of the Kuratorium, the board has established the “Committee for the Extension of the Kuratorium” *(Ausschuss zur Ergänzung des Kuratoriums)*. It meets during the annual board meeting and gives advice on extending the appointment of active board members and suggests new candidates to the ministry.

Looking for suitable candidates for the post of PTB president is another of the Kuratorium’s important tasks. To accomplish this, the Extension Committee – supplemented with other selected individuals – becomes active. The committee obtains an overview of suitable candidates, bearing in mind that the post of president of PTR/PTB demands not only a broad understanding of science – proved, among other things, by outstanding personal scientific achievements – but also excellent management skills. From this group of candidates, one person is selected, presented to the whole Kuratorium and, on their approval, suggested to the Federal Minister of Economics and Technology for appointment. Both the co-optation process for the new appointment of board members as well as the procedure for finding a new president have very much proved their worth over the years.

All in all, looking back at the first 125 years of PTR/PTB shows that the *“Kuratorium”* has proved itself to be highly useful and very successful for the interests of the institute. It serves not only as a scientific advisory board and as an instrument for including the interests of the German economy and of the German consumers, but also acts as a contact and an advisor for the ministry in issues which concern PTB itself and the framework conditions of its work. The *Wissenschaftsrat (German Council of Science and Humanities)* also highlighted this role in its comments on PTB from 2008 [*Wissenschaftsrat, Stellungnahme zur Physikalisch-Technischen Bundesanstalt (PTB), Braunschweig und Berlin, Drs. 8477-08, Rostock, May 2008*]. The success story of the *Kuratorium* meets equally with large interest from visitors from foreign national metrology institutes and from ministries, so that it is to be expected that not only the establishment of a national metrology (research) institute such as the then PTR served as an example throughout the world – and is indeed still doing so – but also the establishment of its advisory board, the *“Kuratorium”*.

1913 – Interference-free magnetic laboratory in Potsdam

After the turn of the century, the electromagnetic interferences on the PTR site in Charlottenburg had reached such an intensity that it was no longer possible to carry out highly sensitive magnetic measurements. The solution to this was the setting up of a new magnetic laboratory far away from the city, on the *Telegrafenberg* hill in Potsdam.

1913 – Walther Meissner starts low-temperature experiments

Walther Meissner, who was a doctoral student of Max Planck and was employed in PTR's Laboratory for Heat since 1908, was commissioned by President Warburg to construct a low-temperature facility which was to enable the investigation of the characteristics of liquid hydrogen and of other materials at these very low temperatures.

1913 Helmholtz-Fonds e. V.

In 1913, members of the *Kuratorium* (Advisory Board) of the PTR established the *Helmholtz-Fonds (“Helmholtz Fund”)* – with the intention of financially supporting physical and technical precision measurements at the PTR.

1914 – Heavy-Current Building – today: Emil Warburg Building

The rapid development of heavy-current technology required the construction of an appropriate building with a machine room having a length of 30 m, a width of 15 m and a height of 10 m, two sides of which were connected to a three-storey laboratory building.

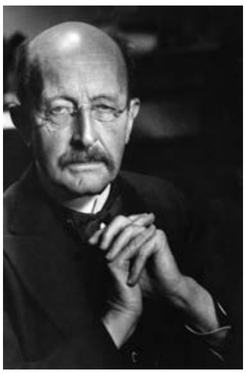
1914 – New organizational structure

President Emil Warburg dissolved the former structure of the PTR (i. e. the sub-division into a “Physical” and a “Technical” Division) and established three new divisions (for *optics, electricity* and *heat*). The aim was to promote the internal cooperation of research and testing tasks in the respective subjects.

1913

1914 – Nobel Prize in physics awarded to Max von Laue

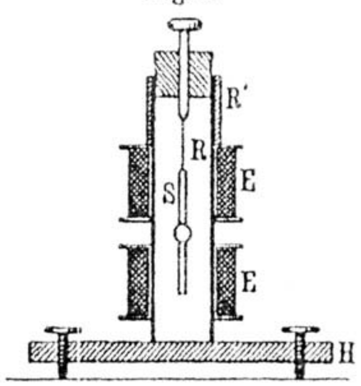
Max von Laue (1879–1960) studied physics in Strasbourg, Göttingen, Munich and Berlin. He obtained his doctoral degree and qualified as a professor under Max Planck. In 1912, he discovered the diffraction of X-rays on crystals and was awarded the Nobel Prize in physics in 1914. He wrote one of the first textbooks on the general and special theories of relativity and thereby helped these to become generally accepted. From 1919 onwards, he exchanged with Max Born as a professor at the University and at the Kaiser Wilhelm Institute for Physics in Berlin and became an advisor of the PTR. In 1943, the National Socialists forced him to retire because of his critical stance. After the war, he was significantly involved in the reorganization of academic activities in Germany, amongst other things the re-founding of PTB in Braunschweig. From 1949 onwards, he was a member of PTB's *Kuratorium*. For the PTB, he became as important as Foerster, Helmholtz and Siemens in former times.



1918 – Nobel Prize in physics awarded to Max Planck

Max Planck (1858–1947) studied physics in Munich and Berlin. As soon as he had returned from teaching in Kiel after four years, he presented – in close cooperation with the experimenters of the PTR – his derived radiation law in the autumn of 1900 which, due to its strict derivation, established the cornerstone of quantum

Fig. 1.



1915 – Einstein-de Haas effect

Einstein, the great theoretical physicist, developed, in cooperation with Wander Johannes de Haas, the only experiment of his scientific career. It was supposed to confirm the hypothesis of Ampère's molecular currents. For this experiment, a small iron bar, which is vertically suspended between two coils and can be turned, serves as a test sample. The rotational vibration of the small bar can be observed as a consequence of its re-magnetization due to current pulses in the coils.

1920 – Gehrcke and Lau measure the fine structure of the H_2 spectrum

Ernst Gehrcke and Ernst Lau measured the fine structure of the hydrogen spectrum at the PTR by means of the Lummer-Gehrcke interferometer. With their spectroscopic work they contributed to the clarification of the atomic structure and to the acceptance of quantum mechanics.

1915 – Mechanical heat equivalent

In a classical mixing calorimeter containing 50 kg of water, electrical heat is released. The temperature increase measured by means of resistance thermometers yields the heat energy in calories which corresponds to the electrical energy in joules. Thus, the "heat equivalent" is determined as (4.1842 ± 0.0008) J_{int}(PTR)/cal15°.

1917 – Wilhelm Kösters becomes head of the Length Measuring Laboratory

In 1917, Wilhelm Kösters became the head of the Length Measuring Laboratory of the PTR. Right from the start, the focus of his scientific work was on the investigation of the potential of a wavelength definition for the base unit the "metre" as well as on the use of combinable gauge blocks for industrial metrology calibrated by means of interference methods.

1920 – Schering Bridge

Harald Schering developed a bridge method at the PTR for the measurement of the capacity and the loss angle at high AC voltages. Thus, for the first time, the dielectrical losses of insulating materials could be examined, and with this knowledge, better materials of this kind could be developed.

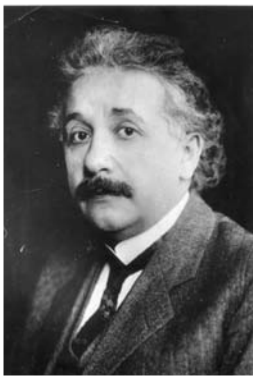
1921 – Nobel Prize in chemistry of 1920 awarded to Walther Nernst

In 1921, Walther Nernst was awarded the Nobel Prize in chemistry of the year 1920 in recognition of his thermochemical work – of which his heat theorem is of particular importance. The prize of 1920 had not been awarded until one year later – as in 1920, none of the nominees had fulfilled the Nobel Prize criteria.

1921

physics at the end of that year. For this, he was awarded the Nobel Prize in physics. In addition to his intensive research work, Max Planck became a busy scientific organizer and was a committed member of the PTR's *Kuratorium* from 1908 to 1935, who strongly engaged in intensifying the research work: "Filling the top positions at the PTR must follow the principle: Employ the best man available."

1921 – Nobel Prize in physics awarded to Albert Einstein



Albert Einstein (1879–1955) studied physics and mathematics at the Polytechnic in Zurich. In 1905, he published his epochal works on the photoelectrical effect, on Brownian motion, on the quantum-theoretical explanation of the specific heat of solids and on the special theory of relativity, which drastically changed the world view of classical physics. Following his lectureship in Zurich, his professorship in Prague and again in Zurich, he came to Berlin in 1914 – amongst other things, at the instigation of the president of the PTR, Emil Warburg – and completed the general theory of relativity. Albert Einstein became a guest scientist at the PTR and a committed member of the *Kuratorium* until his emigration to the United States of America in 1933. He was awarded the Nobel Prize in physics for his explanation of the photo effect. Einstein is regarded as the most significant physicist of the 20^{th} century.

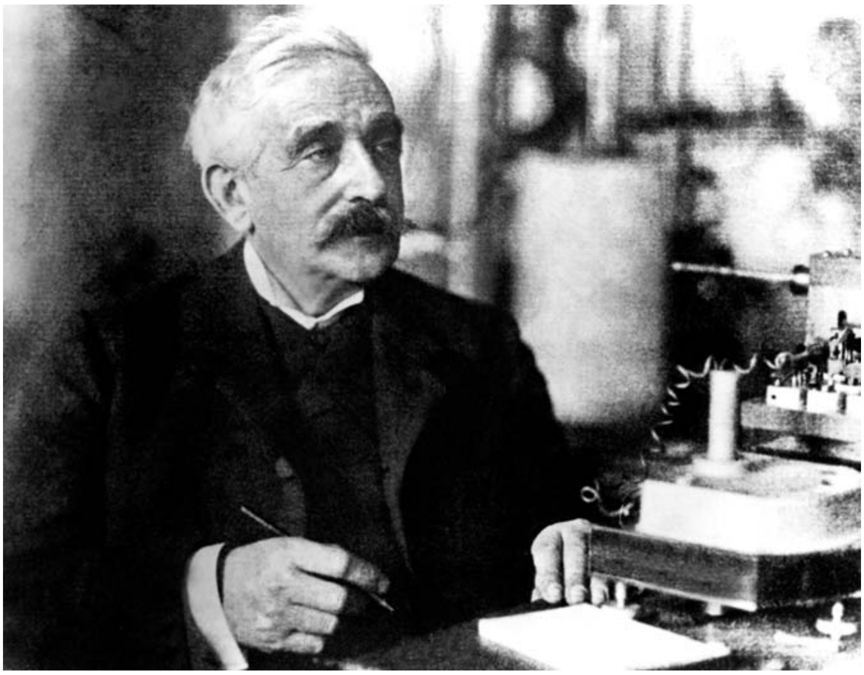
"New Physics" and a New Structure

Wolfgang Buck

It is not unusual that in the course of time, a subject becomes routine and structures become rigid. He who wants to maintain his top position has to accept modern challenges, adapt structures, if necessary, and select the right person for the job. And it does not only have to do with organizational efficiency, but also with opening up new scopes for new issues, and with satisfying staff members' wishes for continued employment and for a career.

Such a situation occurred in 1905 when the president of the PTR, Kohlrausch, retired for health reasons at the end of his mandate. After having been in existence for roughly 20 years, the PTR had established itself and gained a solid reputation worldwide. It had become an outright symbol of Germany's innovative leadership in the field of science and technology. As a result of the obvious advantages it brought about for the domestic industry, other nations, such as Great Britain and the USA, had copied the PTR and founded comparable institutes (the NPL in 1900; the NBS (now NIST) in 1901) which developed ultimately to become serious competitors of the PTR. Inside the PTR, it became obvious that a certain lethargy had started spreading under the leadership of Kohlrausch – with well-defined and routine scientific and technical issues, well-rehearsed workflow and an executive staff who were getting up in the years. Due to financial necessity and a fast growing number of tests to be performed, the Physical Division of the PTR could hardly deal with fundamental physical issues anymore.

Picture below: Emil Warburg, ca. 1920



For the president of the Kuratorium (Advisory Board of the PTR), Theodor Lewald, it was all but an easy task when a suitable successor to Friedrich Kohlrausch had to be found, especially after his favourite candidate, Wilhelm Conrad Röntgen, had declined the offer. Kohlrausch's successor was to have experience in setting up and developing a physical laboratory, he should be aware of the significance of dealing with academic science in order to allow progress as defined by von Siemens and Helmholtz, show excellent organizational aptitudes and be able to interact with the staff members. In addition, he was to be integrated in a network of science and industry, but without compromising the PTR's reputation as a neutral and independent institute.

Lewald finally found such a candidate very close by: Emil Warburg, 58 years old. He had been a full professor for experimental physics at the University of Berlin since 1895 and was also a member of the Academy of Sciences. And last but not least, he had been a member of the PTR's Kuratorium for many years.

With the committed support of the Kuratorium, Warburg repeatedly tried to extend the financial framework of the PTR to be able to afford equipment and hire staff for new fields of research and to be able to pay the employees competitive wages. He did not give up, despite the following – quite cynical – reply from the Ministry: "The PTR has definitely experienced a most favourable development to date. Its performance and expertise enjoy general recognition and esteem. I therefore tend to object to approving of granting the PTR additional funds for salaries in order to maintain excellent scientists and hire additional ones." The PTR was yet in the end granted the resources required to set up a new high-power current laboratory for the Technical Division, today's Emil Warburg Building, and a shielded laboratory for sensitive magnetic investigations at the Telegrafenberg hill in Potsdam. The German electric industry, which was developing fast, needed those facilities.

As the Government refused to increase the funds granted to the PTR, funds for enhanced scientific research had to be sought for outside of public budgets. This eventually succeeded in 1912 on the occasion of the 25th anniversary of the PTR when the "Helmholtz Fund for Scientific Research" was founded; it was fed by large and small enterprises as well as by private individuals with cash contributions amounting to 260 000 marks, hereby generating an annual interest income of 10 000 marks. These funds were to be spent on excellent scientists, on study and conference trips as well as on the purchase of expensive equipment. One year later, Emil Rathenau and AEG's Board of Directors created the foundation "Emil-Rathenau-Stiftung" with assets amounting to 100 000 marks consisting of AEG shares; this foundation pursued the same aims, but was restricted to the fields of electricity and magnetism.

These novel capital sources could be used, in addition to the scarce budget resources, to venture into new fields of research of the so-called "New Physics". Among those were the newly discovered X-rays, the new conception of the atomic structure according to Rutherford and Bohr, Einstein's special theory of relativity, quantum physics based on the blackbody radiator, and the properties of the electron.

The renewal of the research topics of the PTR – and, thus, the PTR's comeback at the forefront of fundamental research – succeeded thanks to two exceptional personalities in the field of research: Hans Geiger and Walther Meissner.

Radioactivity was the new tool to study the atomic structure and first properties of the atomic nucleus. Germany wanted to catch up with France and England, which were the strongholds of this discipline at that time. Hence, it was a fortunate coincidence that Hans Geiger – who, together with Rutherford, had developed numerous detectors for the counting of α-particles since 1907 – wanted to go back to Germany. Warburg succeeded in talking Geiger out of joining the University of Tübingen and in convincing him that the PTR would provide him better opportunities. And this is how it came about that Geiger, from 1912 on, quickly set up a laboratory for radioactivity within the framework of the Optics Laboratory of the Physical Division. Defining units of measurement for radioactive radiation and producing corresponding standards was urgently needed and became Geiger's main task, since the use of radioactive sources in medicine was rapidly increasing. In the remaining time, he was allowed to conduct research on his own; this is how he invented, among other things, the famous "Geiger counter" and developed the coincidence method, together with Walther Bothe who was awarded the Nobel Prize for this in 1954. Together with his team, which at some point also included Walther Meissner and the visiting scientist James Chadwick – who later discovered the neutron – Geiger had very quickly set up a world-class scientific research centre.

Since Kammerlingh Onnes had succeeded in liquefying helium in Leiden back in 1908, the low-temperature behaviour of gases had become an important subject of research, among other things, for a better understanding of the properties of the gas thermometer which was supposed to measure thermodynamic temperature. In 1911, also in Leiden, a new state of matter in solids was discovered – superconductivity. Both thermometry and fundamental physics were a good argument for the PTR to deal with this subject. Walther Meissner, who had obtained his doctoral degree under Max Planck at the University of Berlin in 1907, was also part of the young academics with whom Warburg was intending to venture into highly topical fields of physics. In 1908, Meissner started working at the Heat Laboratory and was soon to become one of the leading researchers in the field of low-temperature physics. In 1913, Warburg entrusted him with setting up a low-temperature facility to investigate the properties of liquid hydrogen. Among the work Meissner began with are investigations of the electric and thermal conductivity of metals between 20 K and 373 K. Unfortunately, World War I thwarted many of these research projects. Hence, only much later was Meissner able to celebrate his great scientific successes, such as the liquefaction of helium in 1925, the discovery of the superconductivity of a series of metals (among them niobium, still the material of choice when it comes to the manufacture of superconducting arrays) around 1928, and, in 1933, the fundamental effect of expulsion of the magnetic field from a superconductor – which, by the way, bears his name.

Besides the orientation towards "New Physics", as is exemplified here, Warburg also had to face yet another problem that has been bothering PTB to this day, namely the relation between fundamental research and the task of disseminating the physical units to industry, science and society through instrument calibrations and type approvals. Hence, a series of parallel laboratories had developed inside the two divisions of the PTR. There were, for example, two laboratories for electricity, two for heat and two for optics which existed side by side.

Ernst Hagen, Head of the Technical Division, addressed a special recruitment problem which arose from the fact that his division was exclusively dedicated to testing: "Without scientific tasks, it would be impossible for Division II to bind suitable civil servants." Here, one senses a subliminal hint of hurt feelings for a loss of prestige vis-à-vis the researchers from the other division.

After several years of debates at the *Kuratorium*, Warburg finally dissolved the two divisions and re-structured the PTR into thematically organized divisions dealing with the following subjects: *optics, electricity*, and *heat* – each of them having a purely scientific sub-division, as well as a sub-division dedicated to testing. Each division was assigned its own director who was responsible for maintaining the link between scientific research and technical work. The president remained the person all divisions had to report to; in addition, he was directly in charge of the Laboratory for High-precision Mechanics, of the Chemistry Laboratory, of the Workshop, as well as of the Shielded Magnetic Laboratory in Potsdam.

Had this new structure not been enforced only two months after the outbreak of World War, it would have immediately had positive impacts. To date, this new structure has provided a fair balance within one and the same organizational unit between the researchers and the scientific staff responsible for testing, and has facilitated the exchange of tasks and experiences. PTB has taken on this – nearly – centennial principle and has even incorporated it in its Terms of Reference for the international evaluation that took place in 2002.

PTB had managed a comeback after its first establishment phase. This was made possible by new financial resources, new relevant physical topics, excellent new staff, new trendsetting structures – and, last but not least, thanks to the new, suitably selected president. ■

The Einstein Case

Dieter Hoffmann

"Warburg intended to 'balance' me to the PTR", could be read in a letter by Albert Einstein dated June 1912. However, the initial plans to induce Einstein to come to Berlin failed. The reason for this might have been that the offered position of an "in-house theoretician" of the PTR did not really attract him, as he had just accepted a call from the renowned Swiss institute, the *Federal Institute of Technology Zurich (Eidgenössische Technische Hochschule in Zürich)* as a well-paid full professor of theoretical physics.

Einstein had become acquainted with Emil Warburg, the president of the PTR in Berlin, at the Solvay Conference in Brussels one year earlier, where the leading contemporary physicists had dealt with up-to-date questions of physics and especially with the quantum problem. Both may have been showing an interest for each other, not least because Warburg was the first to experimentally confirm the photochemical basic law established by Einstein during his fundamental work on the photochemical energy conversion. Also in other respects, Warburg was at pains during his incumbency to open up the research work carried out at the PTR for modern physics and – last but not least – for issues of quantum physics. Part of this concept was to "balance" the 33-year-old Einstein to the PTR – as he had also done with other promising young physicists like Walther Bothe, Hans Geiger and Walther Meissner.

However, when Warburg's efforts failed, his plans were on no account ticked off. Already in the following year, a concerted action of the Berlin physicists was successful, and an attractive offer was used to lure Einstein to Berlin. He became a full-time member of the *Berliner Akademie*, and at the same time he was offered the post as director of a *"Kaiser Wilhelm Institute for Physics"*. As "a paid genius" – as he had once ironically named his position in Berlin – he relocated to Berlin in spring 1914. One of his first scientific activities in Berlin was to follow the invitation of his promoter Emil Warburg and work as a guest scientist at the PTR. At that time, Einstein was not only working on the final definition and formulation of the general theory of relativity, but also on the experimental confirmation of an almost 100-year-old problem – the demonstration of the molecular currents as the origin of magnetism postulated by the French physicist André-Marie Ampère. So far, the assumption had not been proven experimentally, and Einstein himself – together with friends – had carried out quite unsuccessful experiments on this subject already during his time in Bern.

Picture below: André-Marie Ampère (1775–1836), mathematician and physicist, 1825 by Ambroise Tardieu

Picture on the right: Albert Einstein in 1921

In Berlin he followed up on these investigations and hoped to find the prerequisites which were required for the respective precision investigations in the excellently equipped laboratories of the PTR and by means of the scientific and metrological competence of the PTR's staff members. Together with the Dutch physicist Wander Johannes de Haas, who had been a scientific collaborator of the PTR since the beginning of 1914 and who was also a talented researcher in the field of magnetism, he carried out the respective experiments in the winter of 1914/15.

The basic idea of the Einstein-de-Haas tests is the assumption that the magnetic moment of a circular current is proportional to the mechanical angular momentum of the electrons forming the induced circular current. If a cylindrical bar made of soft iron is hung into a coil by means of a thin quartz fibre, and if its magnetic momentum is modified by means of a periodical magnetization of the coil, the iron bar must be excited to make rotary oscillations due to the angular momentum conservation principle. And although the basic experimental set-up seems simple, its experimental implementation was difficult and several artifices were required to separate the expected effect from the multitude of disturbances.

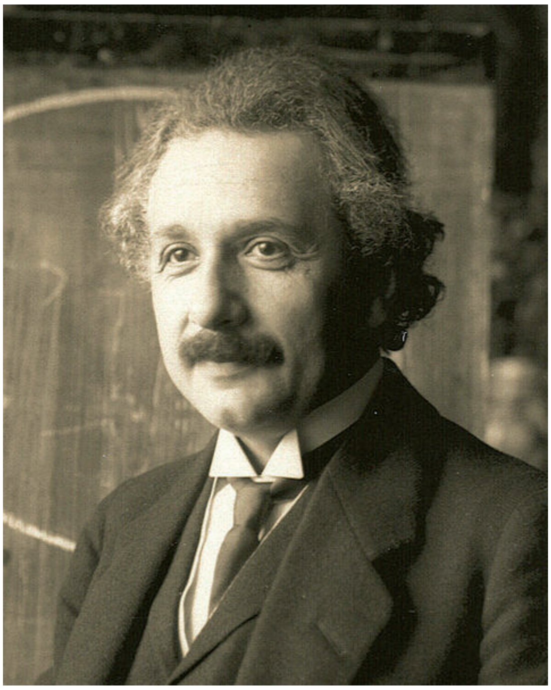
In this respect, Einstein wrote to his friend Michele Besso in February 1915: *"What a wonderful experiment; it is a pity that you are not able to see it. And how treacherous nature can be if you want to cope with it experimentally. I do feel a passion for the experiment in my dotage."*

Already in the colloquium of the Physical Society held on 19 February 1915, Einstein had reported on their successful experiments, and other lectures followed on this subject during the following months. However, it soon turned out that in principle, the experiment had succeeded, but that the determination of the gyromagnetic constant – the relation between the angular momentum change and the magnetization – was much too imprecise. When asserting an agreement between theory and practice, one had – rather – probably followed a theoretical prejudice than the measured data. The correct explanation could only be given when the electron spin was discovered in 1925, which – as is well-known – is decisive for ferromagnetism. Nevertheless, Einstein and de Haas deserve the credit of being the first to (qualitatively) confirm Ampère's molecular current hypothesis.

However, this guest role should not remain the only relation between Einstein and the PTR. In December 1916 he was nominated "by the highest decree" of Emperor Wilhelm II as a member of the *Kuratorium (Advisory Board)* of the PTR. The proposition of appointment submitted to the emperor emphasizes Einstein's outstanding scientific merits:

"Indeed, he is doubtlessly one of the most keen-witted and inventive among the theoretical physicists alive; the theories developed by him in trailblazing works serve as basic principles and guidelines for the research work of numerous national and international experimenters. He also worked as experimenter and recently delivered – in a very important work – experimental proof of the existence of Ampère's molecular currents in magnets. He is also interested in practical questions, so that his contribution to the work of the PTR is particularly promising."

The Kuratorium met once a year in spring, which meant that the function of supervising the activities of the PTR could only be of a very general nature. Einstein had participated regularly in the meetings of the Kuratorium, which mostly lasted three days. It was only towards the end of his time of activity in Berlin that his interest and commitment seem to diminish also in this area. His last two *Kuratorium* meetings were recorded in the year 1927 and 1930, respectively. It seems that in 1930, however, he was only a silent auditor – at least, the minutes did not record any contributions of Einstein to the discussion. In the initial years, this had been different. During that time, Einstein had participated with frequent and pointed remarks in the discussions of the Kuratorium. Thus, it became clear that he was not only a theoretical physicist par excellence, but that he tried to influence the experimental work of the PTR in manifold ways by giving concrete instructions. Furthermore, he took a stand on scientific-political and organizational questions – e. g., on the right of PTR collaborators to file for patents.



In 1921/22, Einstein even seems to have been a *de facto* scientific guest of the PTR. Although there are no concrete proofs of this in the official documents, his correspondence provides the appropriate information. In the summer of 1921, Einstein had conceived *"a very interesting and simple experiment on the nature of light emission"*, by means of which he wanted to intervene with clarifications in the discussion about the wave or particle character of light – which was highly topical at that time. To realize the difficult experiment to examine the character of light emission at channel beam particles, he once again drew on the declared competence and the excellent equipment of the PTR. This time, his congenial partners were Hans Geiger and Walther Bothe of the Laboratory for Radioactivity whose *"excellent cooperation"* soon helped to realize the experiment. As he confessed in a letter to Max Born, it was *"my greatest scientific experience in years"*.

However, his optimism did not last too long – as several weeks later, he had to confess: *"Me, too, I made a monumental mistake some time ago (experiment on light emission by means of channel beams). But, one has to take heart. You will only stop making mistakes after you die"*.

When at the beginning of 1933 the National Socialists came into power in Germany and forced Einstein to emigrate, his relation with the PTR also broke up. In April, the national socialist Ministry of the Interior – which was in charge of the PTR – decreed to delete him from the register of members of the Kuratorium, as he had *"commented on the national renovation of Germany in a way that made his future membership in the Kuratorium of the PTR impossible."*

This was the end of Einstein's relationship with the PTR, which was also not resumed when – after the war – the institute was re-established as the *"Physikalisch-Technische Bundesanstalt"* in Braunschweig. This abrupt end of the "Einstein case" does not appear among the glorious chapters of this institute with its – otherwise, seen as a whole – so very successful history.

1923 – The merging of the PTR and the RMG

A memorandum of the *"Deutscher Verband technisch-wissenschaftlicher Vereine" (German Federation of Technical and Scientific Organizations)* and of the *Normenausschuss der deutschen Industrie (German Standardization Committee)* was the starting point for the merging. In this memorandum, the two organizations complained about the fact that the competencies of the *Reichsanstalt für Maß und Gewicht (Imperial Office for Weights and Measures – RMG)* and of the PTR were overlapping. As a consequence, the RMG was incorporated into the PTR by way of law on 1 October 1923. The RMG was accommodated in a building of the PTR, opposite the "Technical Division". Today, this is the "Wilhelm Foerster Building".

1924 – Bothe and Geiger develop the coincidence measurement technique

By developing the coincidence measurement technique, Walther Bothe and Hans Geiger succeeded in demonstrating that the Compton effect (or "Compton scattering") is the scattering of a photon on an electron. In doing so, they refuted the "Quantum Theory of Radiation" established by Bohr, Kramers and Slater shortly before, which was based on the correspondence principle and according to which the conservation of energy and impulse in the collision process is only valid in the statistic mean.

1925 – New unit for X-ray dose

At the first international congress of radiology, Hermann Behnken from the PTR presented the first definition of a dose measurand for X-ray radiation. The unit of the new measurand "X-ray radiation dose" was called 1 röntgen and was attributed the symbol R. It was defined as the quantity of radiation which generates $2.082 \cdot 10^9$ ion pairs per 1 cm^3 of dry air (ρ = 1.293 mg/cm^3). The unit "röntgen" is no longer admitted today.

1925 – Discovery of the element "rhenium"

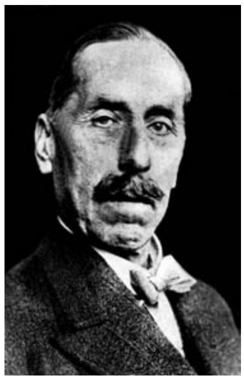
In the Chemical Laboratory, Walther Noddack and Ida Tacke (who was to become his wife) searched for undiscovered elements in the periodic table below manganese. With the support of Otto Berg from Siemens&Halske, they succeeded in detecting the element No. 75 for the first time, by means of X-ray spectroscopy. This element was named "rhenium", in honour of Ida Tacke's home region. In order to eliminate doubts concerning the discovery of this new element, 1.042 g of this rare material were isolated later on from 660 kg of molybdenite, using an extremely tedious procedure.

1922

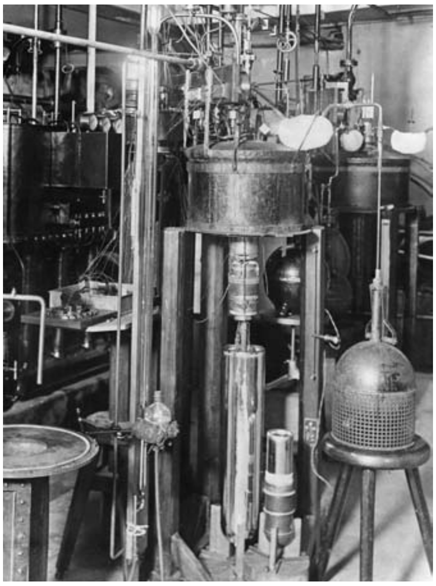
1922 – Walther Nernst becomes president of the PTR

Walther Nernst (1864–1941) studied physics and chemistry in Zurich, Berlin and Graz, obtained his doctoral degree in Würzburg and habilitated in Leipzig. He became a full professor in Göttingen in 1884 before transferring to the *Physikalisch-chemisches Institut (Physical-Chemical Institute)* in Berlin in 1905. In 1891, he developed the Nernst Distribution Law, which is important for chromatography. In 1896, he invented the Nernst lamp which brought him considerable revenue. In 1921, he was awarded the Nobel Prize for Chemistry for his heat theorem from 1905 – also frequently called the 3rd Law of Thermodynamics. He performed both theoretical physics and experimental physics with virtuosity. From 1905 to 1935, he was a member of the "Kuratorium" (the advisory board of the PTR). He was president of the PTR from 1922 until 1924 – times of dire financial straits. He finally left the PTR of his own accord to return to university research. Due to the political situation, he retreated to his estate near Muskau in 1933.

1924 – Friedrich Paschen becomes president of the PTR



Friedrich Paschen (1865–1947) studied physics in Berlin and Strasbourg. In 1901, he became a professor in Tübingen – which, due to his influence, turned into a centre for spectroscopic research. In 1912, he discovered, in collaboration with Ernst Back, the eponymous splitting of the spectral lines in



1925 – Meissner succeeds in liquefying helium

In 1925, Walther Meissner succeeded in commissioning the third helium liquefier worldwide at the PTR; he had conceived this device himself and produced 200 cm³ of liquid helium for the first time in Germany. Thanks to the support of the *Notgemeinschaft der Deutschen Wissenschaft (Emergency Association of German Science)*, the Low-temperature Laboratory of the PTR became something like the national low-temperature lab of the German Empire.

1925 – Max von Laue becomes "external" consultant of the PTR

Max von Laue was already in contact with the PTR during his university studies, via Otto Lummer, and later Walther Meissner. With the support of the *Kuratorium*, Walther Nernst was ultimately able to take on a scientist for theoretical physics, with the aim of strengthening the scientific work at the PTR. Max von Laue had been a full professor of physics at the University of Berlin since 1919, but he took on this external task and came to the PTR once a week.

1926 – Luminous resonators for frequency control

In 1926, Erich Giebe and Adolf Scheibe developed so-called "luminous resonators", in which the mechanical resonance in quartz oscillators was excited by means of high frequency and detected via the resulting flashes in a neon atmosphere. With a reproducibility of 10^{-6}, these luminous resonators are used to control the frequency of tunable transmitters.

1926 – Kösters' comparator

In 1926, a novel interference comparator was used for length measurements on gauge blocks of up to 1 m. A double prism patented by Wilhelm Kösters enabled a compact and air-tight design. By means of a vacuum chamber, it became possible to determine the refractive index of air – and, thus, the wavelength of light – much more accurately than ever before.

1927 – New temperature scale with gold fixed-point

In 1927, the long years of effort on the part of the PTR, the British National Physical Laboratory (NPL) and the American National Bureau of Standards (NBS) were finally crowned with success as the first International Temperature Scale valid over a wide temperature range was adopted. The optical pyrometer was defined as the standard instrument for high temperatures; it is characterized by the freezing point of gold as a reference fixed-point.

1927

a strong magnetic field. He can be considered the greatest spectroscopist of his time; what he most valued was reliable, exact measuring. Paschen became president of the PTR in 1924 and was forced to retire by the Nazis in 1933, after which he taught at the University of Berlin.

1925 – Ida Tacke and Walther Noddack

Ida Noddack, née Tacke (1896–1978) studied – as one of the first women – chemistry at the Technical University of Berlin-Charlottenburg and became a visiting scientist at the PTR from 1924 on. Walther Noddack (1893–1960) studied chemistry, physics and mathematics at the University of Berlin and joined the PTR together with Walther Nernst. There, he became head of the Chemical Laboratory, and, as of 1927, of the Photochemical Laboratory. Noddack's research activities focused on the discovery of unknown elements – which was a prestige project of the PTR – but later also on experiments in photochemistry and geochemistry, amongst other things to find out what meteorites are made of. As far back as 1934, Ida Noddack supposed that uranium nuclei could be split if they are bombarded with neutrons. In 1935, Walther Noddack started teaching in Freiburg, Strasbourg and Bamberg; his wife followed him.

The Merging of the RMG and the PTR

Wolfgang Buck

According to a quotation from Otto von Bismarck, the first Chancellor of the German Empire, the essence of politics is to *"grasp for the hem of God's robe when hearing his footsteps marching through world history"*. This is surely quite a dramatic description, but it precisely reflects the situation of the PTR in the years 1922 and 1923. Due to the galloping inflation, the financial situation of Germany became ever more dramatic. The reparations to the winners of the First World War represented an extreme burden for the budget. For this reason, the new government under Chancellor Wilhelm Cuno, who had been appointed on 16 November 1922, also had to grapple with massive cuts. One of these measures was a simplification of the administration, to which the president of the audit court – as the Governmental Saving Commissioner – was to make proposals. The "reduction in the regular and special staff, if necessary including the abolition of authorities which have become dispensable" was one of the options to be investigated.

In this situation, the *"Deutscher Verband technisch-wissenschaftlicher Vereine" (German Association of Technical-scientific Societies)* and the *"Normenausschuss der deutschen Industrie" (Standards Committee of the German Industry)* presented, on 18 November 1922, a memorandum which criticized that there were certain areas of responsibility of the *Reichsanstalt für Maß und Gewicht (Imperial Institute for Weights and Measures* – RMG) and of the *Physikalisch-Technische Reichsanstalt (Imperial Physical Technical Institute* – PTR) in the field of length measurement which were overlapping and that, thus, *"gauges are tested at two different authorities which partly work with different error limits"*. The memorandum drew the conclusion that *"the RMG and the PTR should be merged to form one single institute"*. This would be *"more economical"*, it would *"merge metrological tasks which otherwise could only be separated with great arbitrariness"* and it *"would put an end to the drawbacks that damage the reputation of the German institutions at home and abroad"*.

Walther Nernst, who had become president of the PTR only a few months before, on 1 April 1922, reacted rapidly. He forwarded, on 19 December 1922, his comment to the Ministry of the Interior, which was responsible for the PTR. Obviously, he realized that in a decision on the future of the two institutions, the overlapping of competencies in the calibration of gauges (which was rather marginal, compared to the total volume of tasks) would, in the precarious financial situation, not be regarded as significant as the savings that would be achieved by a merging of the two institutes. Therefore, he signalized his agreement as follows: *"It must be admitted that the existence of two such institutes in parallel is a luxury which may no longer be justified for our country."* In that connection, he emphatically pointed out, however, that *"on the part of the PTR, no requests for an affiliation of the RMG have ever been expressed"*. Then he filed the petition *"to decide that in accordance with the above statements, an examination of the possibilities for merging the two institutes is realized immediately"*.

Fritz Plato – permanent representative of the extra-official director of the RMG since 1912 and its first full-time director since 1920 – formulated, however, on 22 January 1923, the rejection of the merging by disproving the argument of industry: *"There is not the slightest reason for even considering a merging of the two institutes. The requirements of industry are completely met if the PTR does not exceed its spectrum of tasks and leaves the examination of the length measures to the RMG."* Furthermore, he contradicted the expected saving possibilities. By this, he might have correctly assessed the facts, but completely underestimated the political dynamics which had meanwhile developed.

Although the affiliate members of the plenary meeting of the RMG who had been activated by Plato campaigned for its independence, they then formulated – based on a correct assessment of the situation – conditions for the affiliation of the RMG. The main requirement was that a *"special division is created within the united institute which handles the tasks assigned to it in section 19 of the Ordinance of Weights and Measures completely independently in accordance with the statutes established for the RMG"*. In addition, the responsibility for the verification authorities of the federal states and the cooperation with them – including the plenary meeting – should be continued by the PTR and the competence of the Advisory Board (Kuratorium) be adapted.

After a vivid correspondence and the involvement of both the plenary meeting of the RMG and the "Kuratorium" of the PTR, a cabinet draft of the Minister of the Interior was presented on 10 July 1923 in consultation with the Minister for Economics responsible for the RMG which begins with the following sentences: *"The RMG becomes an independent department of the PTR and is subordinate to a director. The nature of its activity and its responsibility within the scope of the large institution remains unaffected."* The draft comprised nine points and also regulated the partial responsibility of the Ministry of Economics. The "Kuratorium" was extended by a representative of this ministry as well as by one or two representatives of the supreme verification authorities of the federal states and

Picture on the right: Walther Nernst, portrayed by Walter Roth from industrial branches associated with the RMG. Finally, the RMG could preserve all its rights except for its institutional independence. On 20 July, the government agreed. On 26 September, the president signed a corresponding law by which the RMG was incorporated into the PTR effective 1 October 1923, and the merging was formally completed within less than one year. Whether the upcoming retirement of Fritz Plato accelerated the incorporation of the RMG cannot be said. However, it did not get in its way either.

After the die had been cast, a short flashback to the establishment and development of the RMG – which goes considerably further back in history than the PTR – seems appropriate here. Although there is no explicit foundation date of the RMG and its predecessors, two developments showed the direction: in 1806, the "reallocation" of the German political landscape by Napoleon, and the metre definition of 1793, traced back to the circumference of the Earth after the French Revolution.

On 30 November 1806, the old *"Maas-Ordnung"* of 1557 was replaced in the German state of Württemberg by the new *"Maasordnung für die Königlich-Württembergischen Staaten"*. Ten years later, the later *"Königlich-Preußische Normal-Eichungs-Commission zu Berlin"* (NEK) was founded in Prussia as a rather informal institutional structure. It had five unofficial members from the Prussian administration who mainly belonged to the "Prussian Academy of Sciences". Its main task was the calibration of verification standards and the testing of sample measures and weights of other verification commissions as well as the comparison of the Prussian and the new French measures according to the metric system.

After the measures had been standardized in the German states formed by Napoleon, the aim was to standardize all measures throughout Germany. In 1848, the director of the commission, Adolf Brix, elaborated a "New Ordinance of Measures and Weights for the Unified Germany" which was, however, at first not applied because of the political events. Yet, in 1860, a commission appointed by the *Federal Assembly of the German Confederation* in Frankfurt described the situation very vividly: "In Germany, it is often impossible to travel 10 or 20 miles without facing another foot measure, another cubit, another surveyor's measure, another beverage measure or fruit measure. Quantities and names are different, and there is the most multicoloured variety without any principle".

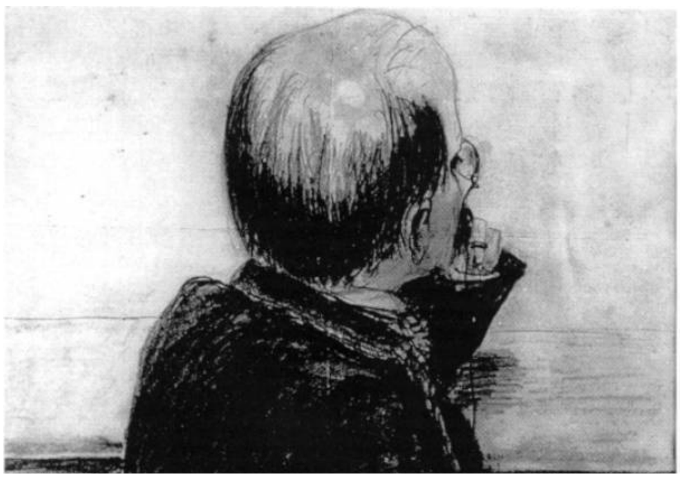
Directed by the *North German Confederation* founded in 1866, a "Measures and Weights Ordinance" was implemented on 17 August 1868 which introduced, for the first time, beginning on 1 January 1870, the metric system for a larger area of Germany. With this law, a *"Standard-verification Commission of the North German Confederation"* (NEK) was established of which the astronomer Wilhelm Foerster was appointed director. He was the driving force which – on the one hand – pushed "metrology" in the field of length and weight measurement within the NEK and, beginning in 1871, as the director of the *"Kaiserliche Normal-Eichungs-Kommission"* (KNEK)), but – on the other hand – from 1872 onwards, he also played a decisive role in the foundation of the PTR because he elaborated – among other things – the tasks and the structure of the Technical Division.

Internationally, the most important task of the KNEK was the German cooperation in the "Metre Convention" created in 1875 by 17 countries. Foerster's outstanding importance for metrology can be most easily recognized by the fact that he was – from the foundation till his death in 1921 – the undisputed German member of the "Comité international des poids et mesures" (CIPM), the steering committee of the Metre Convention, and from 1891 to 1920 – i.e. also during the First World War – its president.

In 1887, the KNEK ceded some test tasks and the whole working field of thermometry to the newly founded PTR; this remained one of the few contact points with it. On 5 September 1918, in the last days of the empire, the KNEK was renamed the *"Reichsanstalt für Maß und Gewicht"*. Meanwhile, it consisted of eight divisions (length measures, weights, balances and weighing machines, standards and measuring tools for liquids, barrels and dry/liquid measures, gas-, water- and vapour-meters, portioning machines, packaging and filling machines, aerometers, chemical activities) and had – in the end – 72 employees.

The restructuring of the PTR, realized by its president Emil Warburg in 1914, facilitated a simple organizational integration of the RMG as the new Division I. Apart from smaller changes, the previous Division 1 "Optics" had to familiarize itself with its new position as number IV. By the extended profile of tasks, the consequences for the PTR and its president became appreciable. Especially the legal obligations of the RMG in the verification system – with a federal structure – aggravated the character of an authority.

It was especially Nernst who – after having diplomatically promoted the merging by his straightforward politics – now felt the increase in the unloved administrative work and the limitation of his scientific opportunities for development particularly bitterly. At the end of February 1924, he finally presented his resignation and resigned from office on 30 April of that year. *Sometimes one grasps the hem of a robe without knowing whether the whole robe will fit*. Nevertheless, Nernst made a central contribution to the "second fundamental event within one century after the restructuring of 1914", as pointed out by Ulrich Kern – an event which decisively changed the "face of the PTR and is perhaps one of the most important events in its history".



1928 – Schering and Vieweg develop compressed-gas capacitor

The Schering bridge requires a standard capacitor which is as far as possible non-dissipative. To this end, Harald Schering developed, in collaboration with Richard Vieweg, a compressed-gas capacitor with a low loss factor – as is still used today in high-voltage laboratories worldwide.

1928 – Kösters uses standard lamp for length measurements

In 1928, Wilhelm Kösters introduced – at the PTR – standard lamps for the interferential length measurement of gauge blocks using the comparator he had developed. For this purpose, precision measurements of the helium and krypton wavelengths were necessary which were related to the metre prototype via the red cadmium wavelength.

1929 – Harmonized definition of the “calorie”

At the 1st *International Steam-Table Conference* held in London, a calorie was, upon a suggestion of the PTR, defined directly via electric energy units as: 1 $kcal_{IT}$ = 1/860 $kW_{int}h$. This “International Table Calorie” replaced several “calories” which had different definitions and, thus, the new definition made this unit independent of the progress achieved in the experimental determination of the thermal capacity of water.

1929 – Bothe and Kolhörster identify cosmic radiation

To clarify the “nature of cosmic radiation”, Walther Bothe and Werner Kolhörster performed coincidence measurements in 1929 using two Geiger-Müller counters and proved that cosmic radiation was not – as had previously been assumed – gamma radiation, but relativistic charged particles.

1930 – Bothe and Becker discover “nuclear gamma rays”

By bombarding light elements with alpha radiation, Walther Bothe and Herbert Becker discovered a secondary radiation of an exceptionally high penetration capability and interpreted it as nuclear gamma radiation. Two years later, James Chadwick showed that these were actually neutrons.

1931 – The CIPM defines an industrial reference temperature

The International Committee for Weights and Measures (CIPM) defines a reference temperature of 20 °C for length measurements.

1931 – The pyrheliometer

A novel pyrheliometer for the determination of the solar constant consists of 2 black bodies whose temperature difference is detected by means of a thermopile. One of the two black bodies is alternately covered by a diaphragm whereas the other one picks up the solar light. The temperature difference between the two is zeroed by an electric heating unit. The radiation power of the Sun is 1.372 cal/(cm² min), measured in Davos.

1928

1928 – Meissner discovers important new superconductors

In 1928, Walther Meissner investigated the question as to whether all metals – provided they are sufficiently pure and the temperatures are sufficiently low – become superconducting, and within a few years only, he discovered the superconductivity of tantalum, thorium, titanium and niobium. The latter, having a transition temperature of 9 K, became the basic material for superconducting circuits – and still is today.

1933 – Walther Meissner

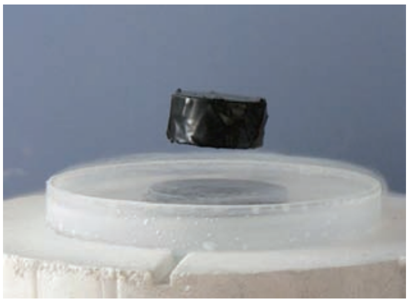
Walther Meissner (1882–1974) studied mechanical engineering at the Technical University of Berlin in Charlottenburg as well as mathematics and physics at the University of Berlin where he obtained his doctoral degree in 1907 under Max Planck. In 1908, he started working for the PTR and set up, amongst other things, the Low-temperature Laboratory, with a hydrogen liquefier and – later – a helium liquefier. He discovered the superconductivity of a series of metals and, in 1933, the expulsion of the magnetic flux, in collaboration with Ochsenfeld. Meissner became a professor at the Technical University of Munich in 1934. From 1947 to 1950, he was the president of the *Bayrische Akademie der Wissenschaften (Bavarian Academy of Sciences and Humanities)*, and from 1949 onwards, he was a member of PTB's *Kuratorium* (Advisory Board).

1932 – Scheibe and Adelsberger develop quartz clocks

In 1932, Adolf Scheibe and Udo Adelsberger developed, at the PTR, the first quartz clocks in Germany, based on luminous resonators. At the beginning of 1932, the first two quartz clocks were connected in continuous operation to the Time Service. Over the years, these quartz clocks turned out to be superior to any pendulum clock.

1933 – Meissner-Ochsenfeld effect

In the course of their experiments in the Low-temperature Laboratory of the PTR, Walther Meissner and Rudolf Ochsenfeld discovered the full expulsion of the magnetic flux from the inside of a superconductor. This effect, which was of fundamental importance for these materials, started being used for perfect magnetic shielding and in other technical applications. With the modern high-temperature supeconductors, the effect can already be demonstrated at temperatures of liquid nitogen.



1933 – Time differences compared to Astronomic Time

By means of PTR's quartz clocks, which had been used since 1933 as frequency and time measures, Adolf Scheibe and Udo Adelsberger demonstrated that the fluctuations measured between their clocks and the time data provided by different time-keeping institutes were mostly due to the fluctuations of the astronomic duration of a day.

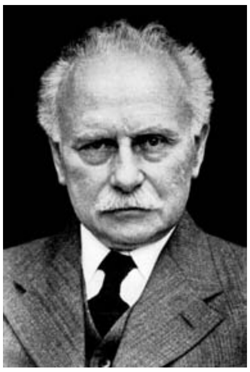
1933 – Kösters determines the wavelength of krypton

Wilhelm Kösters repeatedly investigated the wavelength of the yellow line of the krypton isotope 84 which made coherence lengths over 50 cm possible. Due to the results obtained, the International Committee for Weights and Measures recommended investigating the Doppler effect and the isotope effect in order to reduce the uncertainty of the wavelengths of these lines still further.

1935 – The vaporization heat of water

The vaporization heat of water, which must be known precisely to adjust vaporization processes, was determined in a calorimeter. To this end, water was heated electrically until it vaporized. The boiling point was adjusted by changing the pressure prevailing inside the boiling vessel. The vapour obtained was condensed and weighed.

1935



1933 – Johannes Stark becomes president of the PTR

Johannes Stark (1874–1957) studied physics, mathematics, chemistry and crystallography at the University of Munich. In 1909, he became a full professor at the Technical University of Aachen and later taught at the universities of Greifswald and Würzburg. In 1913, he discovered the splitting of the atomic spectral lines inside the electric field. For this, and for his demonstration of the Doppler effect in canal rays, he was awarded the Nobel Prize in physics in 1919. For personal reasons, he was against Bohr's atomic model, although his discoveries rather backed it. He thanked his post as president of the PTR (from 1933 to 1939) rather to his national-socialist ideas than anything else.

1935 – President Stark dissolves the *Kuratorium*

At the instigation of the president of the PTR, Johannes Stark, the *Kuratorium* (Advisory Board) of the PTR was dissolved on 6 March 1935, the main reason being that it did not correspond to Stark's notion of the *"Führer"* principle.

The Physikalisch-Technische Reichsanstalt in the Third Reich

Dieter Hoffmann

When on 30 January 1933 the National Socialists came into power, this not only signified a serious intrusion into the political life of Germany – with the well-known catastrophic consequences. As in every dictatorship, no area of public life was spared in this political changeover of power with its dominating NS ideology and the power claims connected with it. For the field of science, the exodus of leading scientists – at the apex of which the driving away of Albert Einstein stands symbolically – is the most visible expression of this development. At the same time, there was a successive decline in fundamental research and an increasing orientation towards the political directives for research of the NS state, which were affected by the striving for autarchy and enforced arms build-up. *The Physikalisch-Technische Reichsanstalt* (PTR), too, as largest and most venerable physical research institute in Germany, was not spared from this process, particularly since it was a state institute and since Johannes Stark and Abraham Esau, two exposed followers and advocates of National Socialism, held the office of president in the years of the Third Reich.

Stark, as a long-standing Nazi (National Socialist), was appointed president as early as 1 May 1933 by the Minister of the Interior Wilhelm Frick in opposition to the "unanimous advice of all experts" and developed – after assuming office – first of all, comprehensive plans for reorganization and gigantic new construction plans for the PTR. Although a spatial extension was urgently needed and the PTR had been threatening "to burst at all seams" for a number of years already, the new construction plans (e. g. in Munich) were not even rudimentarily realized. On the other hand, the reorganization and implementation of the *"Führer"* principle in the PTR was conducted with many greater ramifications. In this connection, Stark not only promptly dismissed Albert Einstein and other "Jews and great figures of the old regime" from the Kuratorium, but also forced the general dissolution of this advisory board. Per decree by the Reich Chancellor, this intention was finally, in the winter of 1934/35, complied with and as "Führer" of the institute, the President of the *Physikalisch-Technische Reichsanstalt* was made "fully and totally responsible for the institute in its entirety".

Parallel to the adamant implementation of the "Führer" principle, steps were taken which led to the termination of the agreement with Max von Laue as theoretical advisor of the PTR and – after passing the so-called *Gesetz zur Wiederherstellung des Berufsbeamtentums (Law for the Restoration of the Professional Civil Service)* of April 1933 – to the dismissal of Jewish colleagues (even if their numbers were far below those at the universities). The time of change at the PTR was also characterized by denunciations. In many cases, these denunciations came from members of the NSDAP Factory Cell, which enjoyed great popularity. As early as 1933, more than half of the PTR's personnel were members of the NSDAP. In mid March 1933, H. Beuthe and B. Voigt informed the *Reichsinnenministerium (Reich Ministry of the Interior)* as the superior authority: "On Wednesday, the 8th of March, 1933 at 4:20 p.m., at the instigation of the National Socialist Factory Cell and the National Socialist Civil Servants' Association, the swastika flag was hoisted on the so-called Observatory of the PTR with spontaneous enthusiasm over the enormously successful election. After about one hour, at the instigation of Dr. R. Vieweg and initiated by

Picture below: Blueprint of the new Physikalisch-Technische Reichsanstalt planned for Munich

the President of the PTR, Prof. Dr. F. Paschen, the swastika symbol was pulled down and brought to the flat of the President."

In view of the fact that at that time the days of Paschen's presidency were numbered in any case, this brave deed remained without direct consequences; nevertheless Richard Vieweg preferred – as did many other colleagues – in the autumn of 1933 to exchange his work at the PTR for a professorship at the Technical University of Darmstadt (TH Darmstadt). The departure of such renowned scientists as Richard Vieweg – or Walter Meissner – was caused by the fact that Stark, a difficult person in any case, had, as a representative of "German Physics" and as an exposed opponent of modern physics, work discontinued on a series of relevant research topics.

In order to assume tasks which were of equal importance for both the "promotion of the economy and the promotion of national defence", the activity profile of some of the divisions was changed and the respective new laboratories were established. Of lasting significance was the establishment of an acoustics laboratory in 1934 under Martin Grützmacher. Such a laboratory had already been called for since the 1920s because of the enormous upswing of film, radio and sound transmission technology. Now, due to the increasing technical fields of application, it could finally be realized. Hereby, not only the general acoustic tasks were emphasized, but also – almost equally – the "militarily important tasks". These ranged from the "development of devices for the acoustic finding of artillery positions" to the "use of ultrasound for other military purposes" and to engaging in "encrypting methods".

For the implementation of his reorganization plans and the realization of special research, Stark did not need to settle for the usual budgetary funds as he was able to utilize rather, in addition, the budget allocations of the *Deutsche Forschungsgemeinschaft (German Research Foundation)* – this all the more since he was also its president between 1934 and 1937. A large portion of the newly acquired financial resources were used for renting and equipping additional accommodations and laboratories outside of the ancestral building complex (which was situated in Marchstraße in Berlin-Charlottenburg): for example, in the neighbouring *Franklinstraße*, at the *"Knie" (*today *Ernst-Reuter-Platz)*, and in the *Köpenicker Landstraße*.

In the Third Reich, too, the core task of the PTR, as the supreme metrological institute of Germany, was to maintain the base units and to assure their link-up to the national standards. Thus, in the 1930s, there was an enormously growing amount of testing and verification tasks to handle, whereby in the related traditional fields the PTR still possessed a great reputation and cutting-edge research was conducted. The work of Wilhelm Kösters on the definition of the meter on the basis of the wavelength of light or the work of Adolf Scheibe and Udo Adelsberger on the development of quartz clocks, among other things, attest to this. Furthermore, the discovery of the Meissner-Ochsenfeld effect in the autumn of 1933, one of the most significant discoveries in physics in the history of the PTR, as well as the resulting research conducted by Eduard Justis on superconductivity, but also the discovery of the so-called "exo-electrons" by Johannes Kramer in 1939 document the fact that in individual fields fundamental research was still conducted at a high level.

However, these discoveries were made *not due to* – but rather *in spite of* – the application and militarization tendencies pointed out above, which increased even further under the presidency of Abraham Esau. With Esau, the PTR was headed, since the spring of 1939, by a president who was a renowned high-frequency physicist and – even more than his predecessor – integrated in the political research network of the Third Reich: from his leading position in the *Reichsforschungsrat (Reich Research Council)* as the representative of German high-frequency research and his participation in the *"Uranverein" (Uranium Association)* – staff members of the Radioactivity Division of the PTR (Beuthe, Bomke, Houtermans and Weiss, among others) actively participated in this research – to his connections to military circles and to the armament industry. In contrast to the unrealistic plans of Stark, Esau led the PTR unspectacularly, but efficiently. He was supported thereby by Kurt G. Möller, a former staff member of the *Heereswaffenamt (Army Ordnance Office)*, in the position of vice-president which was newly set up in 1938. However, Möller was not only assigned the part of relieving Esau of routine tasks in view of his diverse research-political duties, but he also managed the forced integration of the PTR in the armament technology network of the Third Reich. Since exact measurements are also a basic requirement for the manufacture of military equipment of all kinds, the PTR gained a key role in armament production and defence engineering during the war. Thus, the number of employees from the reorganization phase continued to grow and the workforce of the PTR was doubled during the war years to more than 700 staff members – with an above-average percentage of women employed.

During the years of World War II, the activity of the PTR was limited more and more to its metrological testing and research tasks for the German civil and wartime economy. There were in the PTR a series of laboratories and divisions which worked exclusively for military bodies. This included the above-mentioned Division VI (Mechanics and Acoustics) under Martin Grützmacher which dealt, among other things, with the sound field of moving ships, which was of top priority for the development of acoustic mines and acoustically guided torpedoes.

After Berlin had become the preferred target of allied air strikes and parts of the PTR had suffered considerable damage from bombing raids, in the summer of 1943 the relocation of the institute was ordered. Thanks to his personal contacts, President Esau could arrange to have a large part of the institute be relocated to Thuringia, "the green heart of Germany", and to find accommodation in a vacant leather factory in Weida near Gera. At the end of the war, about 300 staff members were located there. Due to a shortage of space, branch offices were set up at other sites too – thus, Adolf Scheibe's high-frequency laboratory and the quartz clocks were set up in his hometown of Zeulenroda. The laboratories for nuclear physics and physical chemistry were moved to Ronneburg and Division I for Weights and Measurement went to Ilmenau. Martin Grützmacher and his Acoustics Division wound up in Silesian Warmbrunn. Spared great material losses, the PTR thus remained operable without serious limitations until the end of the war.

1936 – Time measurement for the Olympic Games

On the occasion of the 1936 Olympic Games in Berlin, the finishing line film was used for the first time, in order to clearly determine in which order the athletes had finished and in order to record and determine their running time. The PTR was project leader and worked in cooperation with Zeiss-Ikon Dresden and Agfa-Wolfen to develop a time-measuring system that could be used for all running competitions.

1939 – The Zeesen transmitter emits standard frequency

In February 1939, the short-wave transmitter in Zeesen, close to Berlin, started to emit a standard frequency of 1000 Hz for 8 minutes on week days from 11 a.m. onwards, followed by a four-minute frequency of the standard pitch A (440 Hz). Both frequencies were generated by a quartz clock located at the PTR; they were then forwarded to the broadcasting house.

1939 – Exoelectron emission and the "Kramer effect"

In 1939, Johannes Kramer was the first to study the emission of low-energy electrons from solids after these have undergone mechanical stress, chemical surface reactions or high-energy radiation. He recognized that these are a uniform occurrence.

1939 – Elementary photographic process

At the Photochemistry Laboratory of the PTR, Walter Meidinger discovered the fluorescence of silver halides occurring at low temperatures. With this discovery, he contributed considerably to the clarification of the elementary photographic processes. His investigations led to the extension of the spectral range of films in the X-ray and the infrared range.

1943 – The PTR is relocated to Thuringia

When in September 1939 the PTR's buildings were badly damaged due to the air raids of the allies, the major part of the PTR was moved to Thuringia. The main part was accommodated in the buildings of a former leather factory in Weida. Some of the branches were relocated to Ilmenau, Zeulenroda and Ronneburg.

1946 – Reconstruction of the PTR in Berlin-Charlottenburg

Under the mandate of the "Department for People's Education" of the Magistrate of Greater Berlin, the PTR took up work again, starting with type approvals for measuring instruments and with testing. Under the supervision of Wilhelm Kösters, who was to become the first president of the PTB at a later date, the number of employees increased – until the monetary reform in 1948 – from 20 to 40.

1946 – Foundation of the *Deutsches Amt für Maß und Gewicht (German Office for Weights and Measures* – DAMG) in Weida

By order No. 158 of the Supreme Command of the Soviet troops of occupation in Germany, the *Deutsches Amt für Maß und Gewicht* was founded in Weida on 25 May 1946, using the equipment and staff which had remained from the PTR. Its first president was Professor Dr. Wilhelm Steinhaus, who had been with the PTR for many years.

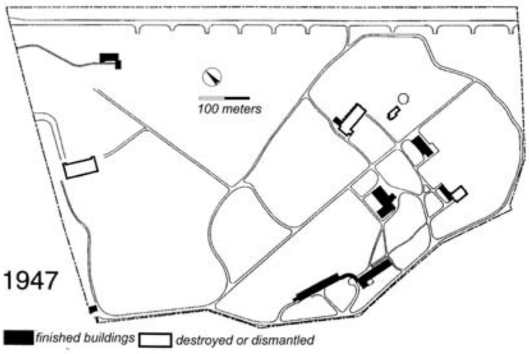
1936

1939 – Abraham Esau becomes president of the PTR

Abraham Robert Esau (1884–1955) studied physics in Berlin and Danzig, and was a student of Max Wien. After World War I, he became the director of all Telefunken laboratories. In 1925, he performed the first VHF transmission between Jena and Kahla. From 1925 on, he became a professor of technical physics in Jena. His field of research remained the very high frequency radio waves and their technical and medical applications. From 1939 to 1945, he was president of the PTR and, simultaneously, *"Commissioner for high-frequency research"* of the National Socialist government. In 1945, he was imprisoned, but in 1949 he was acquitted as "not guilty based on insufficient evidence to prove his guilt".

1945 – For a short time, Wilhelm Steinhaus becomes president of the PTR

Wilhelm Steinhaus (1884–1970) studied mathematics, physics and chemistry in Marburg and Göttingen. He joined the PTR in 1912 as a scientific employee. As an expert in magnetism, he became a laboratory head in 1924 and a head of a division in 1943. The Americans appointed him president of the PTR in Weida in 1945. After the PTR had been dissolved in the Soviet Occupation Zone, Wilhelm



1947 – New beginning in Braunschweig

On the site of the former *Deutsche Forschungsanstalt für Luftfahrt (German Aviation Research Facility* – DFL) in Braunschweig-Völkenrode, a group of PTR employees (mainly from Göttingen and Heidelberg) gathered who had been dispersed during the war. Martin Grützmacher became provisional director of this site.

1949 – The Physikalisch-Technische Anstalt (PTA) gets statutes of its own

On 10 February 1949, before the *Grundgesetz* (German Basic Law) came into force, Ludwig Erhard, in his function as "Director of the Administration of Economic Affairs of the Bizone", signed the *"Statutes of the Physikalisch-Technische Anstalt zu Braunschweig* (PTA)". Thus, the new site became integrated into the administrative structure of post-war Germany as the metrological institute.

1950 – The PTB comes under the auspices of the Federal Republic of Germany

Pursuant to Art. 130, para 1 of the *Grundgesetz (German Basic Law)*, the PTA *("Physical Technical Institute")* was renamed as the *"Physikalisch-Technische Bundesanstalt" ("Federal Physical Technical Institute")* in 1950 and came, in virtue of the ordinance of 8 September 1950, under the auspices of the Federal Republic of Germany.

1950 – Further extension of the Braunschweig site

Due to the strongly growing need for metrological tasks to be fulfilled by the PTB, new buildings were erected in the course of the years, such as the Röntgen, Geiger, Elster-Geitel, Meitner, Hahn and Chadwick buildings.

1951 – Further extension of the PTR in Charlottenburg to three divisions

In 1951, the PTR in Berlin-Charlottenburg was restructured and a division was added. The divisions of the PTR were as follows:
A: Mechanics and Verification;
B: Electrical Engineering;
C: Laboratories for Heat and Pressure, Magnetism and Electrotherapy.

1951 – Engelhard develops the krypton lamp

In 1951, Ernst Engelhard developed a krypton lamp which enables the reproduction of a wavelength with a relative uncertainty of approx. 10^{-9}. Isotope separation and the suppression of the Doppler shift were the starting points for the later metre definition with the orange-red spectral line of ^{86}Kr.

1951

Steinhaus became president of the *German Office for Weights and Measures (Deutsches Amt für Maß und Gewicht* – DAMG) in 1946 until 1957. His efforts to merge the DAMG with the parts of the PTR in the West failed due to the political situation.

1948 – Wilhelm Kösters becomes president of the PTB

Wilhelm Kösters (1876–1950) studied physics, mathematics and chemistry in Münster. Since 1899, he had been employed at the *Kaiserliche Normaleichungskommission (Imperial Standardization and Verification Commission)*. In 1917, he became head of the Length Measurement Laboratory of this commission. In 1923, this authority (which, from 1918 onwards, was called the *"Reichsanstalt für Maß und Gewicht" (Imperial Institute for Weights and Measures* – RMG)) was merged with the PTR. Kösters had become head of Division 1 in 1925. His great metrological aim was to trace the metre back to a natural quantity, such as the wavelength of an atomic transition – which was finally achieved and laid down in 1960. He was president of the PTB from 1948 to 1950 and thus became the first president to rise from within the ranks of the PTR/PTB itself.

The PTR, PTA and DAMG: the Post-war Era

Dieter Hoffmann

In mid April 1945, Thuringia was freed by the Americans troops. However, its occupation by the Americans only lasted two months because, in connection with the Potsdam Conference, the allied troops were to withdraw to the occupation zones agreed upon in Yalta; in return, Berlin, which was occupied by the Red Army, was divided into four occupational sectors. Although American science officers inspected the laboratories of the PTR soon after Weida was freed and asked some of the scientists about their work, the PTR did not, at first, stand in the focus of American interest – as opposed, for example, to the V2 production facility in the Mittelbau-Dora Concentration Camp near Nordhausen or the Carl Zeiss Company in Jena. On 11 May, the PTR was even temporarily closed and a number of the employees were dismissed. To prepare for a relocation of the PTR in connection with the withdrawal of the American troops, the resolution for closure was lifted in June, but then evacuation never occurred – only the most important staff members of the *High-frequency Group* with A. Scheibe and the two quartz clocks, as well as Vice-President Moeller – all in all, 15 scientists and their families – were brought to Heidelberg in June 1945. Likewise, the radium standards of the PTR and a facility for producing polonium were confiscated by the Americans (the radium reserve of the Third Reich held by the PTR had already been brought to Bavaria by Carl-Friedrich Weiss, head of the Radioactivity Division, before the end of the war and there handed over to the Americans in June 1945). The reasons why the entire PTR was not relocated – whereas, in contrast, large parts of the Zeiss Company in Jena and parts of the research potential from the central German industrial locations Wolfen and Leuna, as well as leading scientists of the Universities of Halle, Leipzig and Jena were evacuated to the US Zone of Occupation – are unclear: it may have simply been due to a shortage of time, or the evaluation of the PTR may have been deemed too unimportant, or the aim may have been to avoid further conflicts with the Soviets (which the relocation of a state institute would have undoubtedly provoked).

Above:
Building of the former Dix leather factory in Weida in Thuringia

Picture in the middle:
The badly damaged main building on the grounds of the PTR in Berlin-Charlottenburg in 1945

Picture on the right:
Staff of the PTR branch in Göttingen in 1948

In any case, the Soviet occupational power which marched into Weida on 1 July took over an essentially intact PTR. Scientific commissions came on the heels of the occupation troops. These, however, unfortunately learned that the real "treasures" of the PTR – quartz clocks and radium reserves – were in American hands. The general importance of the PTR seemed to be clear however, because the closure imposed by the Americans was immediately lifted and the staff members were instructed to write detailed reports on their activity; also, the Thuringian state government was instructed to secure the budget of the PTR and, thus, also payment of the salaried employees. By taking these steps, the Soviet occupational power endeavoured to siphon off and make use of the military-technically relevant research of the PTR for its own benefit. Together with the general reorganization of the Soviet occupation policy, the dismantling of the PTR was ordered, however, in the spring of 1946 – only Division 1 (Measures and Weights) remained essentially the same. The dismantling involved a recruitment, i. e. an obligation, of scientists of the PTR for an activity in the Soviet Union, so that the existence of the PTR as a metrological research and verification authority was basically challenged.

That the *Weights and Measures Division* was largely spared total dismantling was probably due to the fact that parallel to the dismantling, efforts were made by the Soviet Military Government to expedite the reconstruction of a functioning metrology and verification system in the Soviet Occupation Zone – an indispensable precondition for the functioning of a modern national economy. To this end, Order No. 158 was adopted by the Soviet Military Administration in Germany on 25 May 1946. This order was earmarked for establishing a *Deutsches Amt für Maß und Gewicht (German Office for Weights and Measures* – DAMG). The seat of this new institute remained Weida for the time being. Not until the early 1950s did the laboratories of the DAMG gradually relocate to Berlin. The new institute was supposed to incorporate the remaining parts of the PTR and to assure the "uniformity of the measures and the accuracy of the measuring instruments in the Soviet Occupation Zone" as central metrological supervisory authority. Wilhelm Steinhaus – previously head of Division 1 – was appointed president of the new institute. The founding of the DAMG can be viewed as the new beginning of national metrology in the Soviet Occupation Zone/German

Democratic Republic, although it had not completely recovered from the bloodletting of the dismantling and the associated profile shift, from which physics research never fully recovered. In this respect, the DAMG and its succeeding institutes during the aftermath were rather in the line of a classical national metrology authority (with the sole task of realizing, maintaining and disseminating the units) than a physical-metrological research institute in the style of the old PTR. This, however, does not mean that research was not also conducted in the DAMG and its succeeding institutes. In some metrological specialist fields, also internationally recognized research accomplishments were attained, however no longer in the depth and the breadth so typical of the activity and the profile of the old PTR.

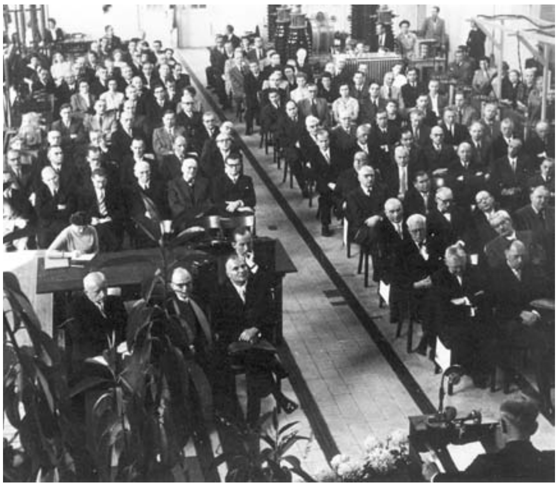
Also in the western occupation zones, the research groups of the PTR had to struggle for their survival, particularly those located in Heidelberg and Göttingen, but also in Eckernförde, Herbstein, Tübingen and Constance. In Berlin, where Charlottenburg now belonged to the British sector of the city, the complicated political and economic situation for a long time prevented a timely reconstruction of the heavily damaged PTR.

Along with the division of Berlin (1948), the value of the activity of the PTR was upgraded, as the PTR was now assigned the sovereign verification tasks for West Berlin – while keeping its name, which did not become obsolete until 1953, when the PTR was incorporated into PTB as the “Berlin Institute”.

Max von Laue became the motor for reactivating the activity of the PTR in the western occupation zones. As early as his internment in Farm Hall, he had developed initial ideas and then, starting from Göttingen in 1946, he managed the reestablishment of the institute. He was supported in his efforts by Martin Grützmacher, who was also located in Göttingen with his Acoustics Division and was endeavouring to become firmly affiliated with this institute.

Von Laue was able to obtain permission from the British occupation authorities that parts of

the abandoned *Luftfahrtforschungsanstalt (Institute of Aeronautical Research)* in Völkenrode near Braunschweig were made available for a reconstruction of the PTR. As vanguard, Martin Grützmacher relocated to Braunschweig in January 1947 with his Acoustics Division. At the same time, a presidential committee was formed in Göttingen under the direction of von Laue, of which such renowned physicists as Werner Heisenberg, Hans Kopfermann and Robert Wichard Pohl were members. This committee conducted the reestablishment of the PTR, including the search for a suitable president. The first step was taken in 1948 with the founding of the *Physikalisch-Technische Anstalt (Physical Technical Institute)*. Thereby, only its previous name “Reichsanstalt” was changed, as the western military governments considered this name no longer opportune because it was too closely connected to the calamitous and atrocious era of the National Socialist “Third Reich” which had just ended, and because Germany was no longer a “Reich” (“empire”) but was developing into a democracy. The continuity in its working profile and its structure as well as in its legal status in comparison to the old PTR was preserved: The institute was to feel equally committed to both legal metrology and scientific metrology and not only be responsible for the “realization, maintenance and development of the physical and technical units of measurement” as the superior verification authority of the nascent “Federal Republic of Germany” but, above all, also address questions concerning physical-technological metrology in its entirety, i. e. also conduct extensive metrological-physical fundamental research. Particularly the latter was understood as a direct continuation of the great traditions of the PTR and marks, in addition, the essential difference to the activity profile of the *Deutsches Amt für Maß und Gewicht (German Office for Weights and Measures* – DAMG) in the German Democratic Republic (GDR). This also becomes clear in the appointment of its president as the attempt was made to obtain a prominent physicist for the still prestigious office – among others, the physio-chemist Paul Harteck and the high-frequency physicist Karl Willy Wagner were under discussion. When this did not succeed, finally in the summer of 1948 Wilhelm Kösters, the long-standing head of Division 1 and director of the Berlin “Rest-PTR” at that time, was appointed the first president of the PTA. Along with Kösters, numerous former staff members of the PTR came to Braunschweig from Berlin, Weida and Heidelberg, so that the construction of the institute received an enduring impulse. In 1947/48 there were already 38 scientists, 47 technicians and 20 labourers again employed in four divisions (Mechanics, Electricity, Heat and Pressure as well as Optics) at the Braunschweig-Völkenrode site. ■



1953 – The PTR in Berlin-Charlottenburg becomes the *"Berlin Institute"* of the PTB

On 25 September 1953, the president of the PTB, Richard Vieweg, welcomed the complete staff of the *"Berlin Institute"* (this became the new name of the former PTR in Berlin, which had come under the auspices of the Federal Republic of Germany) to the PTB in the presence of the Federal Minister of Economics, Prof. Ludwig Erhard, and the Mayor of Berlin, Dr. Walter Schreiber. It should, however, still take several years until the tasks were finally clearly divided among the two institutes and their elaboration optimized.

1952 – The Senate in Berlin decides to merge the PTR with the PTB

After tedious negotiations, the Senate in Berlin finally, on 6 October 1952, agreed to the PTR in Berlin-Charlottenburg being integrated into the PTB in Braunschweig.

1955 – Foundation of the OIML

In October 1955, the convention of the *Organisation Internationale de Métrologie Légale* (OIML) was signed by 16 member states, including Germany. The aim of the OIML is to promote the harmonization of technical procedures in legal metrology and to help thus to remove possible barriers to trade.

1956 – Temperature fixed-points

The International Temperature Scale is based on thermodynamic equilibrium states between the phases of pure substances which can be well reproduced – the defining fixed-points. With their gas thermometer, H. Moser, J. Otto und W. Thomas determined the die freezing temperatures of metals, from the fixed-point of zinc (693 K) to the fixed-point of gold (1337 K), which represented the basis of the high-temperature part of the International Temperature Scale from 1968.

1957 – Redetermination of the ohm

In 1957, the PTB started with a new fundamental determination, namely on the basis of a calculable inductance (ohm coil). With this method, the electric units of inductance, resistance and capacitance can be traced back to mechanical units.

1951

1951 – Richard Vieweg becomes president of the PTB

Richard Vieweg (1896–1972) studied physics and mathematics at the Technical University of Berlin and at the Technical University of Dresden. After obtaining his doctoral degree, he started working for the PTR and soon became the head of the High-voltage Laboratory. In 1935, he followed a call to the Technical University of Darmstadt. From 1951 to 1961, he was the president of the PTB. Richard Vieweg's special focus was on developing international cooperation. From 1960 to 1964, he was the president of the CIPM and considerably involved in the foundation of the *International Organization of Legal Metrology* (OIML).

1951 – Albrecht Kussmann becomes head of the PTR in Berlin

Albrecht Kussmann (1899–1980) studied physics. In 1936, he became the head of the "Magnetic Materials" laboratory of the PTR. After World War II, he became vice president of the PTR in Weida and then took on the same position at the *Deutsches Amt für Maß und Gewicht (German Office for Weights and Measures* – DAMG). He then went to Berlin and became the first president of the

1959 – The DCF77 transmitter in Mainflingen

In 1959, the PTB officially announced the emission of time signals and of the standard frequency via the DCF77 low-frequency (LF) transmitter. In 1970, this transmitter, located in Mainflingen close to Frankfurt, started the continuous emission of time signals. In its 50th year of existence, an estimated 100 million of receivers in Germany and Europe obtained their signal from the transmitter. Via DCF77, the PTB makes the exact time available to its users, with an uncertainty of less than 1 ms and a standard frequency (averaged over one day) having a relative uncertainty of 10^{-12}.

1957 – Optical transfer function

The optical transfer function for the determination of the resolving power of optical systems was developed at the PTB.

1958 – Photoelectric measuring microscopes for length measurement

The first photoelectric measuring microscopes, manufactured by the company "Heidenhain", were installed at the 50 m measuring base in the Abbe building. Through the movement of an oscillating steel string in the image plane of the measuring microscope, the sensitivity of the line capture is increased and the position of the line can be determined independent of the operator.

1958 – Radar measuring devices for traffic monitoring

To improve road safety, the German police was assigned the task of carrying out speed checks of vehicles. For this purpose, the PTB issued the first type-approval certificate for a measuring instrument which worked according to the Doppler radar principle and was able to document the measured values and the traffic situation by means of a photograph.

1959 – Pressure sensitivity of microphones

In 1959, a measuring apparatus was set up to determine the sensitivity of microphones; it covered the total acoustic frequency range. The calibration of microphones became the basis of all noise and sound measurements, especially in the legally regulated area.

1959 – Nuclear fuels

In 1959, the PTB was entrusted with the task of issuing permissions for the transport and storage of nuclear fuels and with the state-controlled safe-keeping of nuclear fuels for which no authorized owner can be found. The mandate to do this was assigned to the PTB in the *"Act on the Peaceful Utilization of Atomic Energy and the Protection against its Hazards" (Atomic Energy Act* (AtG)) of 23 December 1959.

1959

original location of the PTR in Berlin-Charlottenburg and, after the PTR had been integrated into the PTB, he became the director of the "Berlin Institute". During that period, Albrecht Kussmann significantly contributed to the reconstruction of the public metrology system in Germany.

1954 – Walther Bothe is awarded the Nobel Prize

Walther Bothe (1891–1957) studied physics, mathematics, chemistry and music at the University of Berlin; he joined the PTR in 1913 and obtained his doctoral degree in 1914 under Max Planck. Together with Hans Geiger, he developed, at the PTR, the coincidence method to investigate experimentally the Compton effect. In 1930, he became a professor at the University of Giessen, and two years later at the University of Heidelberg. Bothe collaborated in experiments on nuclear fission and built the first German cyclotron particle accelerator back in 1944. Together with Max Born, he was awarded the Nobel Prize in physics for his coincidence method and for the discoveries made thanks to the latter.

Legal Metrology and the OIML

Peter Ulbig,
Roman Schwartz

In practically all nations of the world, there have long been legal regulations for measurements, measuring instruments and the use of measured values. The aim of this is to enable fair trade and to enhance the confidence of the citizens in the reliability of legal measurements. Besides serving legal security, legally regulated measurements also prevent any possible economic damage that might be caused by inaccurate measurements in cross-border trade with bulk goods such as, for example, natural gas or petroleum. But how can it be ensured that the measuring instruments in different countries all indicate the same values within defined maximum permissible errors? Ultimately, this is only possible if the requirements placed on measuring instruments and on the measurement conditions are the same worldwide. These considerations led, in 1955, to the foundation of an international organization of legal metrology with the task of harmonizing the rules and regulations, the technical requirements and the testing procedures for measuring instruments worldwide. This organization was given the name *"Organisation Internationale de Métrologie Légale"* (OIML). The term "legal metrology" encompasses all those activities for which requirements are laid down by the State, e.g. for measurements, measurement units, measuring instruments and measurement methods. These activities are performed by or on behalf of government authorities and are, thus, of a sovereign nature. The field of legal metrology extends from the protection of the population to trading with goods of all kinds and – ultimately – ensures the correctness of measurements everywhere in society, e.g. in commercial exchanges, in official measurements or in measurements carried out within the scope of occupational safety and health protection in general. Legal metrology thus encompasses all those regulations which not only ensure that the measured values indicated by measuring instruments are correct, but also that these values are correctly transmitted, printed and saved. This also includes statistic testing methods such as the ones used, for example, for the checking of prepackages. Legal metrology not only encompasses the requirements placed on the measuring instruments themselves, but also all the regulations that are necessary for legal control and surveillance.

Picture below:
OIML: logo and founding document

Picture on the right:
Seat of the BIML in Paris

ORGANISATION INTERNATIONALE
DE MÉTROLOGIE LÉGALE

BUREAU INTERNATIONAL DE MÉTROLOGIE LÉGALE
11, RUE TURGOT — 75009 PARIS — FRANCE

CONVENTION

INSTITUANT UNE

ORGANISATION INTERNATIONALE

DE MÉTROLOGIE LÉGALE

Signée à PARIS, le 12 octobre 1955
Modifiée en 1968 par amendement de l'Article XIII
(Conformément aux dispositions de l'Article XXXIX)

In our era of globalization, such regulations, however, only make sense if they are applied worldwide. For that reason, the OIML is an intergovernmental organization whose members have – similar to the Metre Convention – signed an international agreement (the OIML Convention) in which they commit themselves to actively participating in the further elaboration and harmonization of rules and regulations in legal metrology and to transposing harmonized technical recommendations that have been published by the OIML into national law.

The OIML Convention was first signed by 16 member states (among them, Germany) in October 1955 and had been ratified in all member states by 1958. Today, the OIML has 57 members and 56 corresponding members. According to data of the World Bank, these 56 member states represent approx. 86 % of the world population and 96 % of the global economy.

In 1991, the OIML certification system was introduced. This system allows the member states to carry out national or regional (e.g. European) conformity assessment procedures on the basis of OIML test and evaluation reports without metrological or technical tests having to be carried out once again in another country. For this purpose, the member states designate so-called "issuing authorities" which are authorized to issue OIML certificates as well as test and evaluation reports for certain categories of measuring instruments. PTB, for example, is notified for 27 categories of measuring instruments, among them non-automatic and automatic weighing instruments, load cells, gas meters, measuring instruments for liquids and length as well as dimensional measuring instruments. In 2006, the – even more binding – "MAA Certification System" was introduced as a supplement (MAA = Mutual Acceptance Arrangement). In contrast to the former "Basic Certification System", the MAA Certification System prescribes that mutual monitoring visits have to be paid at regular intervals (the so-called "peer assessments") or that the bodies involved have to have an accreditation. The aim of this is to strengthen mutual confidence. For manufacturers, an advantage of having been issued MAA certificates is that their access to the countries participating in the MAA is much easier and faster.

The OIML is structured in such a way that the *International Conference for Legal Metrology* (i. e. the "OIML Conference") is at the top of the organization. This conference has been taking place every four years since 1956. At this conference, strategic and financial issues are discussed and decisions on these are taken. Representatives both from the member states themselves and from corresponding members, as well as representatives from international and regional organizations, take part in this conference.

The *International Committee of Legal Metrology* (CIML) acts as the steering body. It meets annually and approves the strategy and action plan, which is updated at regular intervals. Furthermore, it lays down priorities, monitors all technical activities, adopts all the documents and recommendations drawn up by the technical committees, and sanctions new projects. In addition, the CIML monitors the work of the *International Bureau of Legal Metrology* (BIML) and nominates, upon the proposal of the president of the OIML, the director of the BIML as well as the two vice-directors.

The CIML consists of representatives who are nominated by the governments of the member states; to be eligible, these persons must be actively engaged in the legal metrology system. The CIML elects its president and two vice-presidents for 6 years each. At present, the Executive Committee consists of President Peter Mason (Great Britain) and the Vice-Presidents Graham Harvey (Australia) and Roman Schwartz (Germany). To gather personal advice, the president calls in the Presidential Council. This council consists of the president himself and his two vice-presidents, the director of the BIML and five or six selected members of the CIML.

In the 18 Technical Committees and 50 Subcommittees, technical experts specialized in legal metrology agree on documents, recommendations and basic publications. All the activities of the different committees are coordinated by the BIML in Paris. The BIML is composed of the BIML director, the two vice-directors as well as another 8 members of staff. The BIML also organizes technical seminars on topical issues and ensures communication and an international exchange of experiences between technical experts.

In its Technical Committees, the OIML also works out legal regulations which are to serve as models. These are published as international documents and are considered as a framework for the drawing up of national legal regulations. The documents of the OIML are used to an ever increasing extent for the drawing up of national laws. Apart from these documents, there are also OIML "Recommendations". These ensure that the metrological performance of a product (i. e. a measuring instrument) fulfils worldwide uniform requirements and that the testing procedures for certain categories of measuring instruments as well as the respective documentation of the test results are uniform. As already mentioned, this prevents tests from being carried out once again in another country. Besides documents and recommendations, the OIML also elaborates, updates and publishes "Basic Publications", "Expert Reports", "Guides", "Seminar Reports" and the "International Vocabulary of Terms in Legal Metrology" (VIML) which are all made available free of charge on the OIML website (www.oiml.org).

The OIML cooperates with more than 50 international and regional organizations and has, over the past few years, concluded several Memoranda of Understanding (MoU) with numerous partner organizations – among others with the BIPM, ILAC, IAF and ISO – and will soon do so also with the IEC. Good relations exist with IMEKO, UNIDO and the WTO. In addition, the OIML is in regular contact with all regional organizations for legal metrology, such as, e. g., WELMEC in Europe. The OIML's task is to bring these regional organizations together and to work towards a worldwide harmonization of the fundamentals of legal metrology through the exchange of information and experiences. At the same time, new regional or international developments must be picked up and internationally reviewed.

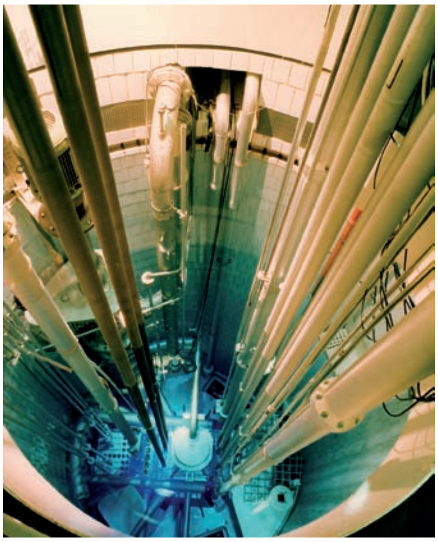
Due to progressing globalization and the increase in international trade and in the exchange of goods, the OIML has, in its more than 50 years of existence, constantly gained in importance. Practically all regions of the world use OIML documents and recommendations as a basis for their own legal regulations. It is mainly the OIML's merit that the barriers to trade for measuring instruments have decreased so considerably. Although modern measuring instruments and measuring systems are becoming more and more complex (for example, the so-called "smart meters"), it will, in future, still be the central task of the OIML to set up technical requirements that have been agreed upon internationally. As the metrological infrastructure is increasingly embedded in a network, the question of how to protect this infrastructure, as well as the question of data security, increasingly gain in importance. Due to this development, the OIML has become the indispensable international switching point of legal metrology. ■

1960 – Definition of the wavelength of the metre

In 1960, the 11th Conférence Générale des Poids et Mesures (CGPM) defined the metre as the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $5d^5$ and $2p^{10}$ of the ^{86}Kr atom. This definition is based on the preliminary work of Wilhelm Kösters and Ernst Engelhardt at the PTR and the PTB who, for decades, investigated the suitability of different spectral lines for interferometric length measurements. The development led to the Engelhard lamp, by which it became possible to realize the unit of length 100 times more accurately than with the international prototype of the metre.

1965 – Roughness standards for industry

By means of a precision grinding process, surface roughness standards were manufactured in 1965 which, for the first time, allowed surface measurements with contact stylus instruments to be objectively compared and, thus, led to improved process control. Today, the standards are known worldwide as "PTB roughness standards".



1967 – The research reactor FMRB

On 3 October 1967, a self-preserving chain reaction of nuclear fission was, for the first time, generated in the *Forschungs- und Messreaktor Braunschweig (Experimental and Research Reactor Braunschweig* – FMRB). The FMRB had the task to produce neutrons for fundamental research, to test and to calibrate measuring instruments and to develop new measurement procedures for dosimetry.

1962 – The Josephson effect

In 1962, Brian D. Josephson described the tunnelling current between two weakly coupled superconductors (Josephson contact). Josephson contacts are metrologically important because they form the core piece for both the Josephson voltage standard and superconducting quantum interferometers (SQUIDs) which are developed intensively at the PTB and used as electric precision sensors.

1968 – Line standard comparator with laser interferometer

For use on a line standard comparator supplied by the company "Heidenhain", 2-mode frequency-stabilized He-Ne lasers and electronic evaluation units for a heterodyne interferometer were developed at the PTB.

1960

1961 – New name for the DAMG

The *Deutsches Amt für Maß und Gewicht (German Agency of Weights and Measures* – DAMG), founded in 1946 in the Soviet Zone of Occupation, was renamed as the *Deutsches Amt für Messwesen (German Agency for Metrology* – DAM). On the territory of the GDR, it had taken on the tasks of the former PTR. Also the verification boards and the verification authorities came under its control. After its amalgamation and restructuring, the *Deutsches Amt für Messwesen (German Agency for Metrology* – DAM) of the German Democratic Republic was renamed as the *Deutsches Amt für Messwesen und Warenprüfung (German Agency for Metrology and Materials Testing* – DAMW).

1961 – Martin Kersten becomes president of the PTB

Martin Kersten (1906–1999) studied physics at the Technical Universities of Berlin and Stuttgart. From 1946 on, he held the chair in experimental physics at the Technical University of Dresden, after that at the University of Jena. In 1951 he was offered a chair by the Technical University of Aachen and left the German Democratic Republic. From 1961 to 1969, he was president of the PTB. With Kersten, a scientist with industrial experience – gained, e.g. at Siemens&Halske and Vakuumschmelze Hanau – became head of the PTB. During his term in office, important decisions were taken, for example, the extension of the working field "industrial metrology" and the construction of the experimental and research reactor.

1969 – Caesium atomic clock CS1

Shortly after the redefinition of the unit of time in 1967, the PTB presented its primary caesium atomic clock with an estimated relative uncertainty below 10^{-12}. As a result of constant further development and characterization, an uncertainty of approx. $3 \cdot 10^{-14}$ was already achieved in 1986. Through that, CS1 has, for a long time, been the most exact clock in the world. In 2011, CS1 had – with a few interruptions – been operated in continuous operation for more than 40 years and is still used as the primary standard for German and international time.

1969 – Verification and Units Act

In 1969, a series of PTB tasks – such as, for example, the realization of the legal units as well as type examinations for measuring instruments – were laid down in the Units and Verification Act. Still today, these legally defined tasks rank – in addition to basic research – among the most important tasks of the PTB. As a higher federal authority, the PTB is responsible for the supervision of metrology.

1970 – Base-circle-based involute standards

In 1970, the development of base-circle-based involute standards and of the associated measuring device allowed for the first time a high-precision, but simple calibration of gear measuring instruments.

1972 – Cryogenic comparators improve current measurement

Current comparators allow the ratios of electric currents to be traced back to winding number ratios. With specially shaped superconducting shieldings which must, however, be operated in liquid helium, the ratio errors of classical comparators are avoided. In 1972, the PTB achieved an improvement by four orders of magnitude to $1 \cdot 10^{-10}$.

1972

1970 – Ulrich Stille becomes president of the PTB

Ulrich Stille (1910–1976) was the last doctoral student of the Nobel Prize winner James Franck in Göttingen. Stille obtained his doctoral degree at the Technical University of Braunschweig, joined the later PTB in 1948, headed the "Mechanics" Division in 1958 and became vice president in 1969. He was president of the PTB from 1970 until 1975. His book *"Messen und Rechnen in der Physik"* *("Measuring and Calculating in Physics")*, which was published in 1955, became a benchmark of metrology.

1972 – First uniform value for the Josephson constant

After four national metrology institutes – in the USA, Great Britain, Australia and Germany – had succeeded in reproducing the voltage unit "volt" with the aid of the Josephson effect, a first value was determined by the Metre Convention for the Josephson constant $h/2e$. The relative overall uncertainty achieved by the PTB amounted to $4 \cdot 10^{-8}$.

1974 – Ion accelerator

After a construction period of two years, the ion accelerator facility in today's Chadwick Building, composed of a Van-de-Graaff accelerator and a cyclotron, was put into operation. With it, the PTB had the "most efficient state-of-the-art devices" available at that time for the generation of fast neutrons.

1973 – The DAMW turns into the ASMW

After its amalgamation with the *Amt für Standardisierung (Office for Standardization)*, the name of the DAMW of the German Democratic Republic was changed into *Amt für Standardisierung, Messwesen und Warenprüfung (Office for Standardization, Metrology and Quality Control* – ASMW).

1973 – Helmholtz Prize

In 1973, the *Helmholtz-Fonds ("Helmholtz Fund")* for the first time announced the Helmholtz Prize, on the occasion of its 60th anniversary. Since that time – i.e. since the foundation of this prize – the Helmholtz Prize has been awarded for outstanding scientific and technological research work in the field of metrology at intervals of two or three years.

1975 – First coordinate measuring machine at the PTB

At the PTB, coordinate measuring technology was developed from gear and thread metrology. The first coordinate measuring machine was supplied by SIP. In the same year, the company "Zeiss" made another machine available to the PTB as a loan.

1976 – Disposal of radioactive waste

The responsibility for the establishment and operation of facilities of the Federal Government for the long-term management and disposal of radioactive waste was assigned to the PTB by the Atomic Energy Act (AtG) of 30 October 1976. Herewith, the PTB acted in accordance with the technical instructions of the federal minister responsible for nuclear safety and radiation protection.

1973

1975 – Dieter Kind becomes president of the PTB

Dieter Kind (born in 1929 in Reichenberg/Bohemia) studied at the Technical Universities of Berlin and Munich. He obtained his doctoral degree in the field of high-voltage technology. After a longer period of work in industry, he was offered a chair by the Technical University of Braunschweig. With Dieter Kind, for the first time an engineer assumed the office of the president of the PTB. His presidency lasted for 20 years. The reunification of Germany and, thus, also the reunification of metrology as well as the subsequent restrictive staff policy of the Federal Government were great challenges he had to face during his term in office. From 1984 to 1996, Dieter Kind was also president of the *Comité International des Poids et Mesures* (CIPM) of the International Metre Convention.

1977 – Foundation of the DKD *(German Calibration Service)*

With the foundation of the *Deutscher Kalibrierdienst (German Calibration Service* – DKD), private laboratories were given the possibility of obtaining an accreditation by the PTB, authorizing them to perform calibrations for industry on their own. Thereby, the major part of the calibration process could now be carried out by the private sector, whereas the PTB could limit its work to a few orders which placed particularly high requirements – in particular if these orders required a direct comparison with the national standards. The PTB had overall responsibility for the DKD.

1978 – Time Act

In 1978, the task of realizing and disseminating time, which is decisive for public life in Germany, was assigned to the PTB by means of the Time Act. Central European Time (CET) or Central European Summer Time (CEST) are derived at the PTB directly from the caesium atomic clocks.

1979 – Foundation of BESSY

On 5 March 1979, the basic agreement on the establishment and operation of the 800 MeV electron storage ring facility BESSY (Berlin Electron Storage Ring for Synchrotron Radiation) – later called BESSY I – was signed, among others by the PTB.

1979 – Cooperation with China

After contacts between PTB scientists and Chinese metrologists had been maintained since 1976, Germany and China concluded a first agreement (firstly valid for five years) on a close cooperation in the field of metrology. In the following decades, it has been prolonged at regular intervals.

1979

1977 – Plan-approval procedure for the Gorleben repository

After the government of the federal state of Lower Saxony had agreed to examine applications for the establishment of an atomic waste management centre on the Gorleben salt dome, the PTB filed, in the summer of 1977, the respective plan-approval application in accordance with its competence established in the Atomic Energy Act.

1977 – Plasma diagnosis

In 1977, the spectral dispersion of the hydrogen resonance lines L_α and L_β in plasmas of high density was, for the first time, measured as an indicator of the plasma state free from reabsorption in cold peripheral zones, and proof of the influence of the ion movement on the Stark dispersion was furnished.

1977 – The composition and the tasks of the Kuratorium are reorganized

On 16 August 1977, new statutes of the PTB were published in the Federal Gazette which, in section 8, replaced the composition and tasks of the Kuratorium which still originated from the times of the PTA. The number of consultants and their terms of office were limited and the selection procedure specified.

1980 – Commissioning of the Berlin Magnetically Shielded Room (BMSR)

The BMSR is an accessible magnetically shielded chamber whose walls consist of a copper layer (for eddy current shielding) and 6 layers of Mu metal (a highly permeable alloy). For many years, this was to be the magnetically "quietest" room on Earth, in which measurement technologies for the investigation of biomagnetic fields – for example of humans – were developed.

1980 – Quantum Hall effect for the reproduction of the unit "ohm"

Together with its discoverer, Klaus von Klitzing, the winner of the Nobel Prize in physics in 1985, the quantum Hall effect was measured and its suitability for high-precision reproduction of the ohm, the unit of the electric resistance, was detected. From 1990 onwards, by an international agreement, the quantum Hall effect has become the basis for resistance measurements worldwide.

1981 – Redefinition of the Avogadro constant

On the way towards a redefinition of the Avogadro constant, the lattice constant of natural, single-crystal silicon was measured with a precision of $6 \cdot 10^{-8}$ (which had so far not been achievable) and published in the scientific journal "Physical Review Letters".

1982 – Plan-approval procedure for the repository "Schacht Konrad"

After the presentation of the positive research report of the *"Gesellschaft für Strahlen- und Umweltforschung"* on the suitability of the *"Schacht Konrad"* metal mine near Salzgitter, the PTB filed the application for the initiation of the plan-approval procedure for a repository for weakly radioactive waste and waste from closed nuclear installations.

1980

1985 – Klaus von Klitzing is awarded the Nobel Prize

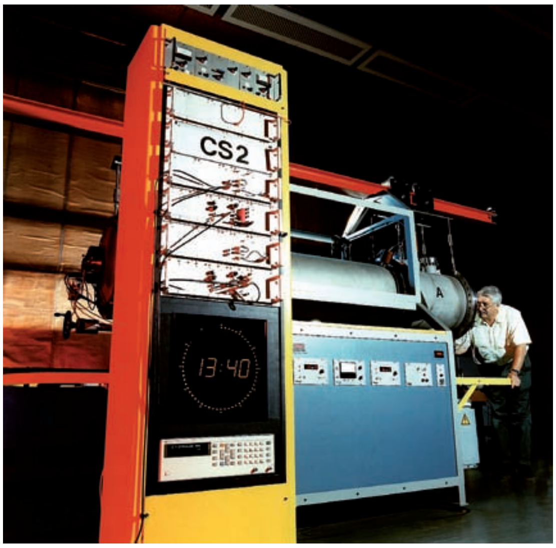
Klaus von Klitzing (born in 1943 in Schroda/Posen) studied physics in Braunschweig. He obtained his doctoral degree and habilitation at the University of Würzburg. For the discovery of the quantum Hall effect, he was awarded the Nobel Prize in physics. This effect has played a decisive role in the redefinition of the unit of resistance "ohm". Klaus von Klitzing is a member of the Board of Directors at the *Max Planck Institute for Solid State Research* in Stuttgart. His close connection to the PTB and his personal commitment were emphasized by his role over many years as the deputy president of the *"Kuratorium"* (the advisory board of the PTB).

1984 – BESSY becomes primary radiation standard

In January 1984, regular user operation of the storage ring BESSY was started. The PTB was able to show very quickly that BESSY could be used as a calculable standard of spectral radiance – i. e. as a primary standard – from the infrared to the range of soft X-rays.

1985 – Chaotic laser emission

In 1985, theoretical predictions that the laser emission would have to become chaotic for certain laser parameters were, for the first time, confirmed in experiments at the PTB. With lasers in the infrared and in the visible spectral range it was confirmed that chaotic dynamics is typical of the complete class of optically excited gas lasers.



1986 – Second Cs atomic clock CS2

In 1986, the PTB put its second primary caesium atomic clock CS2 into operation. With a relative uncertainty of $2.2 \cdot 10^{-14}$, it is the most precise clock of its time and allowed, for the first time, also the estimated uncertainty of CS1 to be checked. For 24 years, it worked in continuous operation before its caesium stock had to be renewed in 2010.

1987

1987 – Foundation of EUROMET

In 1987, 14 (later 15) European countries agreed on a close metrological cooperation under the umbrella of EUROMET. In the subsequent years, the voluntary amalgamation developed into an effective and indispensable organization for metrology in Europe. With the fall of the "Iron Curtain", the number of members increased to 25, later to 33.

1987 – 100 years of PTR/PTB

As the PTB is the successor of the PTR, it celebrated its 100th anniversary in the presence of the Federal President and many guests from home and abroad. The 28th of March 1887 is regarded as the foundation day of the PTR. It is the day when the Imperial Diet approved for the first time an annual budget of 75,000 marks.

European Metrology

Wolfgang Schmid

Approximately three decades ago, the first Regional Metrology Organizations (RMOs) were founded and tailored according to the trading regions of the world. The intention of founding these RMOs was to create forums for coordinating the work of the National Metrology Institutes (NMIs). Although a cooperation within these RMOs did not bring about any legally binding obligations for the members, it turned out to be extremely successful: colleagues working in the same fields of metrology, but at different NMIs of a region, started to exchange scientific information; furthermore, they supported each other in tracing their national standards back to the International System of Units (SI), carried out comparison measurements and cooperated in joint research projects.

In Europe, this cooperation was, for a period of 20 years, successfully coordinated by EUROMET, the *European Collaboration in Measurement* Standards. With the signing of the Memorandum of Understanding (MoU) in Madrid in September 1987, EUROMET had become the successor of the Western European Metrology Club (WEMC) that had been founded in the 1970s. EUROMET was open to all NMIs of the European Community and of EFTA, and also to an organization of the EU Commission analogous to these: the *Institute for Reference Materials and Measurements* (IRMM). After the metrology institutes from Central and Eastern Europe had joined EUROMET after the end of the division of Europe, the NMIs from 33 European countries were members of this cooperation. In 1988, P. Dean from the National Physical Laboratory (NPL) in Great Britain was elected as EUROMET's first chairman. Its last chairman was, until 30 June 2007, Michael Kühne from PTB.

From the end of the 1990s, there were two topics which essentially determined the work of EUROMET:

- the conclusion of the Mutual Recognition Arrangement of the CIPM (CIPM MRA) and the spectrum of tasks resulting therefrom for EUROMET as the metrology organization (RMO) for Europe;
- the plans to intensify – in view of the increasing metrological requirements which were to be expected and the limited national financial resources available – the cooperation within Europe.

The signing of the CIPM MRA, in 1999, on the mutual recognition of the national standards and of the calibration and measurement capabilities (CMCs) associated with these was an important milestone for international metrology. It guaranteed that calibration certificates issued by the NMIs were internationally recognized after they had undergone a detailed capability check, in which the RMOs play a central role. In the cooperation with the BIPM and with the other RMOs within the scope of the "Joint Committee of the Regional Metrology Organizations and the BIPM" (JCRB), EUROMET has always played an active role and has essentially contributed to the shaping of the basic principles of the MRA.

The question as to how the metrological landscape in Europe will have to develop in the 21st century in order to be able to meet the requirements of science, society and the economy was the impetus for the EUROMET study "MERA" ("Planning the European Research Area in Metrology"). This study, carried out by nine European NMIs in the period between September 2002 and November 2003, was supported by the EU within the scope of the "Competitive and Sustainable Growth" programme. The core thesis of this study can be summarized as follows: *The carrying out of joint research & development projects must become the core task of EUROMET*. This encompasses metrological research & development in order to promote the competitiveness of the European industry and to maintain and improve the quality of life in Europe.

The MERA study was followed by the iMERA project "Implementing the European Research Area for Metrology", an ERANET project which was co-financed by the EU within the scope of the 6th Framework Programme. The number of iMERA partners increased to 20, among them five ministries of European countries. The main aim was to create the framework conditions for the NMIs to carry out a research programme in metrology (EMRP = "European Metrology Research Programme") based on Article 169 of the EC Treaty. This article states that the EU can participate in financing the execution of a project which is carried out by several member states if the European Parliament and the Council of Ministers of the EU give their approval. For the project partners, the main tasks were:

- to set up an organization capable of carrying out such a European research programme, and
- to elaborate the contents for the EMRP for a period of 7 years.

The different possibilities for setting up such an organization were intensively discussed with all members of EUROMET. Finally, the founding of a new organization called "EURAMET" ("European Association of National Metrology Institutes") was determined which has taken on the activities of EUROMET and organizes, in addition, the EMRP.

Picture on the right: Inauguration of EURAMET, 11 January 2007 in Berlin

Picture below: EURAMET logo

EURAMET European Association of National Metrology Institutes

As a registered association, EURAMET has legal capacity, which means that in the execution of a European research programme, it may act as a contracting partner of the European Commission. On 11 January 2007, the time had finally arrived: EURAMET, a registered association domiciled in Braunschweig, was founded at PTB's Berlin Institute. Michael Kühne was elected as its first chairperson. On 1 July 2007, EURAMET started its work as Europe's regional metrology organization and was officially recognized by the BIPM as the successor organization of EUROMET within the scope of the CIPM MRA. After that, EUROMET was dissolved.

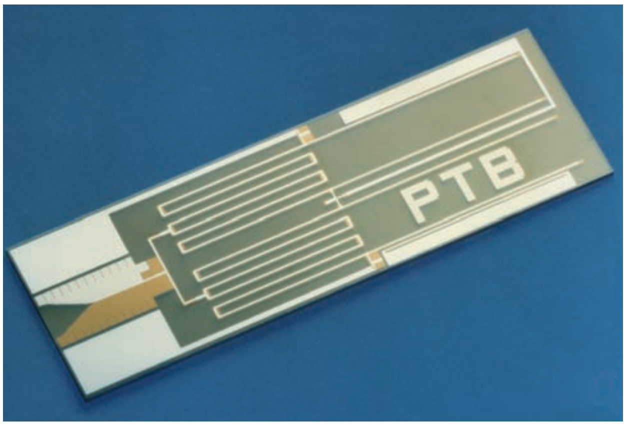
Meanwhile, EURAMET has 37 European NMIs as members, as well as the IRMM of the European Commission and 71 designated institutes as associated members. The central decision-making committee is the General Assembly in which each member-NMI is represented by a delegate. All decisions concerning the EMRP are taken in an EMRP Committee of its own. EURAMET is led by a chairperson and two vice-chairpersons and supported by the Board of Directors which consists of the three chairpersons and six elected members. The general management tasks and the administrative tasks are carried out by the Secretariat which has its seat on the site of PTB in Braunschweig. For EMRP's management, a branch office was established which is domiciled at the NPL in Teddington (UK). These permanent structures ensure the continuity of EURAMET's work.

Parallel to the activities of iMERA, which were aimed at creating the structures for an EMRP, work for the elaboration of the contents of the EMRP started. The aim was to obtain support from the EU on the basis of Article 169. The Commission was in favour of this project from the start, but there was some delay due to the limited financing possibilities. The Commission therefore first offered – as a temporary solution – financing within the scope of the newly created ERANET Plus Programme. As early as in 2007, iMERA Plus had been approved by the Commission with a total volume of € 65 million (€ 21 million of these from the EU) for a term of 3 years, and prepared by EURAMET. In 2008, 21 research projects were launched which are all based on the basic principle of several NMIs cooperating with each other in "Joint Research Projects" (JRPs). The procedures used by EURAMET to assess the projects have proven their worth. Especially the centralized selection procedure on the basis of a "review conference" has turned out to be an excellent means for assessing a project in a competent and balanced way.

In mid-2009, the European Parliament and the Council of Ministers approved a larger programme within the scope of Article 169, with a total volume of € 400 million (50 % of these from the EU) and for a term of 7 years. The first call in the field of "Metrology for Energy" was already issued in the same year. The corresponding projects started at the beginning of 2010. Since then, calls in various fields of metrology have been issued annually. An overview of the current – and of the still upcoming – JRPs and calls is available on EURAMET's website [EMRP – Calls and Projects, http://www.euramet.org].

The creation of EURAMET and the successful realization of the European Metrology Research Programme (EMRP) are important development steps for European metrology. But although this EMRP was the motivation for a further development of the European metrological structure and the foundation of EURAMET (whose core activity it is), this is, by far, not the only challenge EURAMET will have to face in the future. The aim is also to develop a well-balanced programme in all relevant fields of cooperation, with the results of the EMRP being made available to a larger circle than just to the institutes which are directly involved in the project. An important mission of EURAMET is, for example, to support "new" members in setting up their national metrology infrastructure; this is achieved by means of training measures and consultation programmes.

In 2011, EURAMET formulated its "Strategy 2020" which reads: "Our vision is to be the leader in the development and application of measurement, enabling Europe to be competitive, healthy and sustainable through innovation."



1987 – Josephson voltage standard

The generation of the voltage unit 1 V with a reproducibility of approx. $7 \cdot 10^{-13}$ was achieved with the aid of a series array of 1400 Josephson tunnel junctions. The frequency of the microwave fed into the Josephson voltage standard was stabilized to the atomic clock of the PTB.

1987 – First measurement of magnetic signals from the brain stem

In the 1980s, magnetic encephalography (MEG) – the magnetic equivalent of the EEG – was an emerging discipline. The investigations were, however, limited to cortical biomagnetic signals, as the detection of deeper sources was regarded as being unmeasurable until a team of staff members of the PTB and of the University of Münster succeeded in detecting – in the BMSR – biomagnetic signals from the brain stem.

1987 – Conformity in audiometry

Thanks to the introduction of metrological controls for audiometers, the human “golden ear” of the audiometrist was replaced by a metrologically verified calibration.

1989 – New authority for radioactive waste and nuclear fuels established

On 9 October 1989, the responsibility for the long-term management and disposal of radioactive waste as well as for the government custody and the approvals for the transport and storage of nuclear fuels was transferred – with the *Law on the Establishment of a Bundesamt für Strahlenschutz (Federal Office for Radiation Protection* –BfS) – to this new independent higher federal authority within the portfolio of the Federal Minister for the Environment, Nature Conservation and Nuclear Safety. The PTB division that had assumed these tasks so far was integrated into the BfS. The management of the operation of the respective facilities of the Federal Government and of all documents was ceded to the BfS.

1990 – WELMEC Memorandum of Understanding

On 8 June 1990, WELMEC, the *European Cooperation in Legal Metrology*, was founded when representatives from 13 European nations signed a Memorandum of Understanding. Today, a total of 37 nations cooperate within WELMEC. Meanwhile, also contacts with other European and international organizations have been established.

1987

1990 – The International Temperature Scale of 1990 (ITS-90)

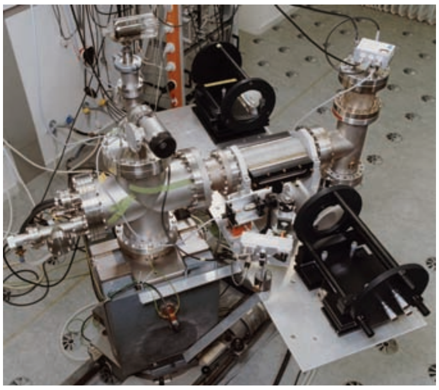
Since the end of the 19th century, a constantly developed and improved international temperature scale has guaranteed worldwide uniform temperature measurements. The ITS-90 valid at present extends from 0.65 K up to the highest temperatures which can be measured by Planck's radiation law. The radiation-thermometric measurements performed by Hans-Joachim Jung and Joachim Fischer at the PTB provide the basis of the high-temperature range of the ITS-90.

1990 – Taking over staff from the ASMW

Within the scope of the Unification Treaty, the PTB took over, in 1990, 365 permanent employees and 50 having a contract for 18 months, mainly from the *Department of Metrology* of the *ASMW (Office for Standardization, Metrology and Quality Control* of the former German Democratic Republic – GDR). Thanks to the excellent collaboration of all the persons involved, nearly all of these employees received their employment contracts before Christmas, thus holding a piece of bright future in their hands.

1991 – Restructuring of the PTB after German Reunification

In March 1991, President Kind presented the memorandum *“PTB after the German Reunification”*, which describes PTB's new structure for mastering the tasks efficiently in reunified Germany. The staff taken over from the ASMW were assigned posts in Braunschweig or Berlin-Charlottenburg (depending on their field of work), with the aim of establishing them there in the medium term. In Berlin, two new divisions as well as an administrative unit and a unit for the technical infrastructure were created.



1991 – Atom interferometry

By means of a rotating calcium atom interferometer it was shown at PTB in 1991 that the rotation rate can be read out as a phase shift or as a frequency shift of the atomic waves via the Sagnac effect. Today, twenty years later, most accurate gyroscopes are being developed with the aid of this effect, and they are equivalent to the best mechanical gyroscopes and laser gyroscopes.

1991 – Heisenberg Building

In 1991, the Heisenberg Building, a laboratory building specifically conceived for electric precision measurements, was inaugurated. In this laboratory – designed to realize, maintain and disseminate the electric units ohm, volt and ampere – the influence of electromagnetic, climatic and mechanical disturbances is minimized.

1992 – First activities in *"Metrology in Chemistry"*

In 1992, the setting up of a laboratory for *"Metrology in Chemistry"* triggered off systematic activities for the traceability of analytical measurements in chemistry to the International System of Units (SI) at the PTB. Initially, the activities were focused on the realization of the pH scale and the evaluation of isotope dilution mass spectrometry (IDMS) for use in metrological traceability. These activities were linked to the foundation of the *Consultative Committee for the Amount of Substance* at the Metre Convention and of the corresponding EUROMET Subject Fields in 1993.

1993 – Clean Room Centre

By building the Clean Room Centre, PTB contributed, in 1993, to the promotion of precision metrology as this field of work increasingly required manufacturing procedures for nano-electric circuits and quantum standards. Furthermore, it became more and more necessary to strengthen the field of "Electric Quantum Metrology" and to perform tasks in micro- and nanometrology, in high-precision angle and multiaxial metrology, as well as in optical metrology in a low-particle environment.

1993

1993 – Metrological Scanning Tunnelling Microscope (STM)

In 1993, the so-called "metrological scanning tunnelling microscope" was realized for the first time worldwide. This measuring instrument is especially characterized by the fact that the displacement of the sample relative to the tip is measured with great accuracy by means of capacitive sensors. This method enables traceable length measurements on conductive nanostructures.

1993 – Cuts in staff

With the 1993 Budget Act, an annual reduction of staff began. The aim of these cuts originally was to reduce the number of federal employees back to the previous number of staff prior to German Reunification. Despite the fact that this aim was reached already in 2007, PTB had, by the end of 2011, lost 425 permanent posts – although in two evaluation reports (which had yielded excellent results) warnings had been raised that such cuts in staff might have negative effects on the national economy.

1993 – Angle comparator

In 1993, the angle comparator was developed in cooperation with the Heidenhain Company. This comparator allows the most accurate measurements of the plane angle over the full range of 360° (U = 0.002") by using air bearings as well as two integrated angle encoders which can be adjusted in the relative positions.

The Reunification of Metrology in Germany

Dieter Kind

In 1987, in the year of the 100th anniversary of the PTR/PTB, the division of Germany into two separate states had firmly lodged itself into the consciousness of most people. The "Iron Curtain" went straight through Germany, and the "Berlin Wall" erected around West Berlin appeared, apart from a few politically intended exceptions, to be impassable. In particular, for the staff in the Metrology Department of the *Amt für Standardisierung, Messwesen und Warenprüfung (Office for Standardization, Metrology and Quality Control* – ASMW) in the east of the divided city, contact with PTB's Berlin Institute was completely ruled out by the politics of the German Democratic Republic (GDR). Accidental personal meetings at the periphery of international events remained rare exceptions.

Nevertheless, the president of the ASMW was invited to the Anniversary Celebration of PTB on 27 March 1987 in West Berlin. The invitation letter remained, however, unanswered. All the same, the president of PTB addressed this in his speech: *"Unfortunately there is still only very little direct cooperation between PTB and the ASMW. We hope, however, that the commemoration of the foundation of the PTR 100 years ago will, in the future, also here lead to forms of cooperation, as are usual in metrology throughout the world."*

Picture below: Meeting at the 100-year anniversary celebration in Braunschweig: Federal President Richard von Weizsäcker, PTB President Dieter Kind and ASMW President Helmut Lilie (from the left)

Picture on the right: Title page of *PTB-Mitteilungen* on the reunification of metrology in Germany

Later that year, the undeniable shared history of PTB and the ASMW did, however, still lead to unofficial signals which, in turn, led to the president of the ASMW being allowed – with permission from the highest level – to accept an invitation to the Ceremonial Event at PTB in Braunschweig on 6 October 1987. In this context he wrote that *"we will extend and organize our cooperation"*. PTB's president greeted him with the words: *"With him I share the hope that his presence will be the start of a fruitful cooperation between the ASMW and PTB. I am sure that the staff of both institutions will gladly take up all the possible ways of enabling scientific exchanges."*

On its return to East Berlin, the ASMW delegation was able to report that in Braunschweig there had been *"no political or scientific discrimination against the GDR, no attempts at enticing scientists away from the ASMW, and no use of wrong or imprecise names"* of the GDR or the ASMW, and that even a meeting with the Federal President had taken place. The path was thus free for the development of the cooperation. Due to the activities of PTB, the ASMW also wanted to raise its international significance in its anniversary year; it, however, chose the politically uncontroversial title "100 Years of State Metrology" for its "Ceremonial Scientific Colloquium" on 10 December 1987. Even the president of PTB was involved with a welcoming speech. For political reasons he was, however, not addressed in this capacity but only as the president of the CIPM. Following this, leading PTB staff members visited the laboratories of the ASMW in Berlin-Friedrichshagen for the first time and, while doing so, received information about the structure, the fields of work and the experimental facilities of the "Metrology Department". This opportunity was used to raise the first considerations about scientific exchanges, and the development of a future cooperation was discussed.

After the fall of the Berlin Wall on 9 November 1989 later called the *"Wende" ("political change"*), the first democratic elections to the East German Parliament (the "People's Chamber") on 18 March 1990, the coming into force of German Monetary Union on 1 July and the signing of the Unification Treaty on 31 August, the path was free for the GDR to join the Federal Republic of Germany on 3 October 1990. As a direct consequence of the political reunification of Germany, the ASMW was disbanded in accordance with the Unification Treaty and PTB was ordered – by a decree of the Federal Ministry of Economics – to establish a branch at the 23 ha site in Friedrichshagen. For many of the approximately 3000 employees last working there, this development initially meant some uncertainty about the basis of their professional existence, in the end, however, also a well-founded hope for a positive future.

The employment contracts of the ASMW staff members were extended until 31 December 1990, apart from those of executives who had had management posts above the level of ASMW's

Divisions. The 500 Berlin staff in the Metrology Department were thus also able to continue their work at first. Despite the large difficulties caused by the lack of telephone and transport connections with Friedrichshagen, most of ASMW's personnel was able to be taken on by PTB in Friedrichshagen, Charlottenburg or Braunschweig in time after re-applying successfully for their jobs. To this end, 365 permanent positions and 50 temporary jobs limited to 18 months were approved in a supplementary budget.

The Federal Minister of Economics had not only transferred the Friedrichshagen site with all its facilities and buildings to PTB, but also the fiduciary administration of the verification system agencies which were later to be taken on by the "New Federal States". This large additional task was mastered in cooperation with the "Old Federal States". In this way, many of the employees of the ASMW's Metrology Department from outside Berlin were also able to continue their career paths later on in the five "New Federal States" in an appropriate way.

Earlier suggestions for joint metrological projects had given PTB an insight into the internal organizational and technical workings of the ASMW which had been treated as secret up till then. Good personal connections also soon developed between the parties involved. As early as 27 April 1990 a reasoned rough structure for the integration of part of the staff employed in East Berlin in the Metrology Department – oriented on the scope of the tasks – was presented to the Federal Ministry of Economics, and met with the agreement of the Ministry.

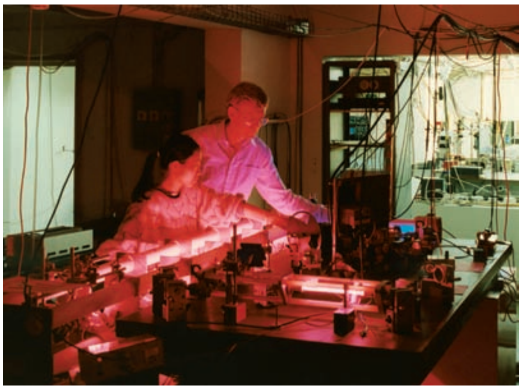
What with hindsight seems to be a normal administrative procedure was, in reality, an act of strength undertaken with great personal effort, which PTB staff from the scientific divisions and, in particular, also from the administrative sections had to perform in close cooperation with the staff council. After all, security about their professional perspectives had to be given to the new colleagues in as short a time as possible. By the end of 1990, about 80 % of all the appointment procedures had been completed. The acceptance of this process was, however, made somewhat difficult through the different salaries awarded to employees in the East and in the West.

A year later, at its meeting in Berlin on 22 April 1991, a memorandum "PTB after German Unification" was presented to PTB's Kuratorium (Advisory Board). The discussion of this important document resulted in the basic approval of an expanded structure in Berlin. From about the middle of 1991 the "Temperature and Synchrotron Radiation" and "Medical Metrology and Information Technology" Divisions were to be set up in Charlottenburg. Apart from this, the "Institut Berlin" was also to be responsible for the infrastructure in Friedrichshagen giving new meaning to its traditional name. The focal points of the work there were, among other things, specified as "Metrological Services" and "Metrological Information Technology". Furthermore, some of the laboratories were to be managed technically by the respective divisions in Braunschweig and Charlottenburg.

The long-term future of the – then – three PTB sites needed particularly serious planning. The main issue was if PTB could not forego one of the three sites in the long term to reduce the time and effort spent on infrastructure. A memorandum entitled "PTB 2000" correspondingly came to the following conclusion: Giving up the Braunschweig site seemed to be out of the question as first-rate buildings and facilities for demanding experimental work were available there on an ideal 100 ha large site. The Charlottenburg location was the traditional site of the PTR for which Werner von Siemens had conveyed the property to the German Empire from his own personal assets. This location in the centre of Berlin is of special value and is also indispensable to PTB because of its proximity to universities, hospitals and other scientific institutions. Similar arguments could not be found for Friedrichshagen. Compared to Braunschweig and Charlottenburg, the fabric of the buildings and, above all, the infrastructure were urgently in need of repair. It was hardly possible to envisage a future PTB project, that could not be realized better at one of the other two locations.

From today's point of view the plan to voluntarily give up the Friedrichshagen site step-by-step within a decade showed itself to be economically unavoidable. Understandably, this decision was a disappointment at first for the former employees of the ASMW, yet they ultimately clearly welcomed the fact that they were informed about a possible relocation of their work place to PTB in good time. Wherever they were employed over the years, they won – up to the management level – high approval through their specialized competence and their dedicated way of working.

In fact PTB took leave of the Friedrichshagen site in a dignified manner on 2 October 2001 in an event which many guests and above all former ASMW staff took part in. The Physikalisch-Technische Bundesanstalt was thus able to do justice to its responsibilities – which were growing because of German reunification and because of globalization – in a concentrated space with strengthened personnel.



1995 – Optical atomic clock

In 1995, the first phase-coherent measurement worldwide of an optical frequency by direct comparison with a caesium atomic clock was performed at the PTB. With the specially set-up frequency synthesis chain, the frequency of a laser, which is stabilized on a narrow optical transition in the calcium atom, can be divided down in the radiofrequency range without losing one cycle of the optical frequency. The whole arrangement is the first example of optical atomic clocks and will, in future, outperform the primary caesium atomic clocks with regard to stability and accuracy.

1994 – Multi-channel system for biomagnetism in hospitals

At PTB's laboratory at the *University Clinic Benjamin Franklin* in Berlin-Steglitz, a biomagnetic measuring system was commissioned in 1994; its core piece consists of 83 SQUID magnetometers. This facility, which was developed by PTB itself, is – still today – considered as the most sensitive multi-channel SQUID system worldwide. It is used by numerous interdisciplinary research groups as an investigation device for cardiological, neurological, gastroenterological, biochemical and physical experiments.

1995 – Vacuum Ultraviolet (VUV) solar radiometry

On 2 December 1995, the SOHO solar observatory of the ESA and NASA was launched with VUV spectrometers on board measuring the VUV radiation of the Sun with an unheard of accuracy thanks to a calibration that is traced back to the electron storage ring BESSY I.

1995 – Comparator for measure and form

In the Clean Room Centre, a comparator developed at the PTB was put into operation which could achieve (so far unattained) measurement uncertainties of 20 nm for diameters of external and internal structures.

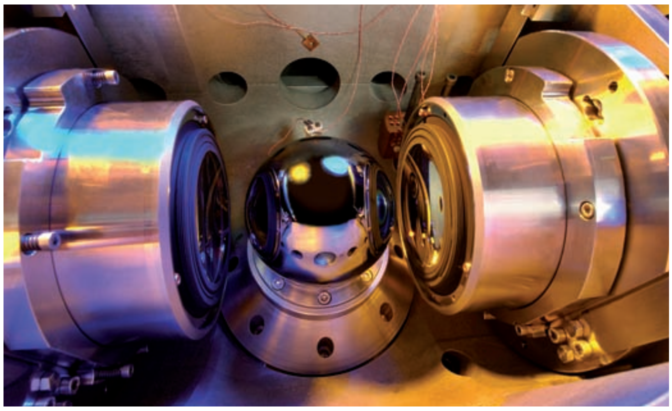
1995 – FMRB out of service

The *Forschungs- und Messreaktor Braunschweig (Experimental and Research Reactor Braunschweig* – FMRB) was finally shut down on 19 December 1995, as its operation was no longer economically justifiable.

1994

1995 – Ernst O. Göbel becomes president of the PTB

Ernst O. Göbel (born in 1946 in Seelbach) studied physics at the University of Stuttgart where he also obtained his doctoral degree and his habilitation. In 1990, he was awarded the Max Born Prize of the *Deutsche Physikalische Gesellschaft (German Physical Society)* and of the English *Institute of Physics*, in 1991, the Gottfried Wilhelm Leibniz Prize of the *Deutsche Forschungsgemeinschaft (German Research Foundation)*, and in 2010 the *Bundesverdienstkreuz (Federal Cross of Merit)*. He was president of the PTB from 1995 until 2011. Despite progressing globalization and the need for cost-cutting, he succeeded in ensuring the high quality of PTB's research. From 2004 to 2011 he was, in addition, president of the *Comité International des Poids et Mesures* (CIPM) in Paris.



1996 – Commissioning of the first 3T whole-body MR tomograph

The PTB in Berlin was the first institution in Germany to put into operation a whole-body magnetic resonance tomograph (MRT) with a 3-tesla magnet. During the subsequent 10 years, the MRT was to be used for the development of novel MR technologies for medical imaging and spectroscopy as well as for investigations made into patient safety.

1996 – Setting up of the first sphere interferometer

The setting up of a basic novel optical multiple-beam interferometer with spherical reference faces by Gerhard Bönsch und Arnold Nicolaus allowed the extremely exact detection of complete diameter topographies of reference spheres and – thus – provided the basis for the later redefinition of the Avogadro constant.

1996 – Calculation of measurement uncertainty by means of simulation

The universal calculation module VCMM allowed, for the first time, the automatic calculation of a task-specific measurement uncertainty for arbitrary prismatic specimens on coordinate measuring machines. In 2002, its designers were awarded the Technology Transfer Prize of the City of Braunschweig for this.

1998 – Microprobes

In cooperation with external partners, microprobes were developed for the three-dimensional detection of microstructures. The procedures realized, which had successfully been transferred to industry, comprised the tactile-optical sensor as well as the first measuring 3D microprobe on the basis of silicon microtechnology (2004).

1999

1999 – End of operation of BESSY I – Start of BESSY II

On 29 and 30 March 1999, the laboratory of the PTB at the electron storage ring BESSY II was inaugurated in Berlin-Adlershof. It became possible to extend radiometry with synchrotron radiation up to the range of hard X-radiation. BESSY I was shut down on 26 November 1999.

1999 – Bilateral agreement with Japan

The Japanese National Research Laboratory of Metrology and the PTB signed a bilateral agreement on the mutual recognition of the test results of non-automatic weighing instruments. This was a milestone on the way to the removal of technical barriers to trade for the weighing instrument industry of the two countries.

1999 – Realization of the electrical power

In 1999, the PTB presented a new procedure for the realization of the electrical power with a relative uncertainty of 10^{-6}, for which AC voltages and alternating currents are traced back to DC quantities by means of sampling technologies.

1999 MRA of the CIPM

With the CIPM MRA, a worldwide “mutual recognition arrangement” of test certificates of national metrology institutes was formulated which was signed by 38 member states of the Metre Convention. Its purpose is to facilitate global trade.

1999 – High-pressure natural gas standard

To harmonize the traceability chains for high-pressure natural gas volume measurements in Germany and the Netherlands, the PTB and the *Van Swinden Laboratorium* (VSL) and – beginning in 2004 – also the *Laboratoire national de métrologie et d'essais* (LNE) in France agreed on the definition of a uniform reference level – the "Harmonized European Gas Cubic Meter" – for the dissemination of the volume unit of high-pressure natural gas.

1999 – Microwave and optical clocks are connected via the frequency comb

Theodor W. Hänsch, a member of the PTB's *Kuratorium*, invented the femtosecond frequency comb which can be used to couple arbitrary frequencies in the optical spectral range directly with two frequencies in the radio-frequency range. Besides many applications of this novel white light in precision spectroscopy and technology, the frequency comb is a universally applicable "clockwork" for optical atomic clocks and helped these to become broadly accepted. In 2005, this achievement was honoured with the Nobel Prize in physics.

2000 – 2 MN force standard machine

The worldwide second largest force standard machine with a direct deadweight effect (50 load disks with a total mass of 200 t) was transferred from Berlin-Friedrichshagen to Braunschweig, modernized and put into operation again. The machine, which had been built at the former ASMW in 1979, had a total height of 17 m, achieved a measurement uncertainty of $2 \cdot 10^{-5}$ and guaranteed the metrological traceability of all force measurements from 200 kN up to 2 MN in Germany and abroad.

1999

2000 – Nanometer comparator

For the first time, a machine design optimized for fault avoidance or compensation, as well as the interferometric displacement measurement under vacuum conditions, allowed measurements at length divisions up to 610 mm with uncertainties in the nm range. The measuring instrument – the so-called "nanometer comparator" – was developed in cooperation with the Heidenhain company.

2000 – Inauguration of the Hermann von Helmholtz Building

After the elaborate restoration of the former *Arbeitsschutzmuseum (Museum of Occupational Safety)* in Berlin-Charlottenburg, which had burnt down during World War II, this historic monument was re-opened on 20 October 2000 as the Hermann von Helmholtz Building.

2000 – Nanostructure investigations

Since 2000, a scanning probe microscope has been equipped with laser interferometers in the scan axes and thus allows the traceable dimensional calibration of nanostructured measurement objects over a measurement range of 70 µm.

2000 – Thermal neutron field at the GKSS

At the research reactor FRG-1 of the ***G**esellschaft für **K**ernenergieverwertung in **S**chiffbau und **S**chifffahrt mbH* (GKSS) in Geesthacht, the reference field of the PTB for thermal neutrons was put into operation.

2000 – The caesium fountain clock

In 2000, the characterization of the newly developed caesium fountain clock CSF1 was completed. In this clock, caesium atoms are laser-cooled down to 2 µK and run on a ballistic trajectory to achieve the longest possible request time. With a relative uncertainty of $1.5 \cdot 10^{-15}$, CSF1 contributes to the realization of International Atomic Time.

2000 – Berlin Magnetically Shielded Room II

Within the scope of the new use of the Hermann von Helmholtz Building, ideal conditions for the metrological infrastructure of the "Biosignal" Department were created. The setting up of the BMSR II was the most spectacular event; it clearly exceeded the specifications of the BMSR I and is still considered to be the magnetically best shielded room worldwide. In addition to biomagnetic measurements at the limit of measurability, investigations on polarized noble gases are carried out which are only possible in that room.

2000 – Heat meter test section

The new heat meter test section at the Hermann von Helmholtz Building in Berlin is the largest test facility of its kind worldwide and has a large dynamic range (volume flows of 3 m³/h up to 1000 m³/h, temperatures of 3 °C up to 90 °C). It is used for type approval tests as well as for numerous research projects.

2000 – Provisional Low-Temperature Scale PLTS-2000

In October 2000, the International Committee on Weights and Measures (CIPM) adopted an extension of the temperature scale ITS-90 – the *Provisional Low-Temperature Scale from 0.9 mK to 1 K* (PLTS-2000). The new scale – in the development of which the PTB was strongly involved – is, in the first place, important for fundamental research and for the manufacturers of cryostats for ultra-low temperatures. It uses the phase equilibrium between the liquid and the solid phase of the lighter helium isotope ^{3}He.

2001

2001 – Closure of the site in Berlin-Friedrichshagen

Within the scope of German Reunification, the site of the *Amt für Standardisierung, Messwesen und Warenprüfung (Office for Standardization, Metrology and Quality Control* – ASMW) of the German Democratic Republic in Berlin-Friedrichshagen had been transferred to PTB. After that, a process of concentrating tasks on two sites only, in Braunschweig and Berlin-Charlottenburg, had started which took more than 10 years. It was concluded with a festive farewell party on 2 October 2001.

2001 – Bilateral agreement with the Chinese AQSIQ

In 2001, PTB and the Chinese AQSIQ (State General Administration of People's Republic of China for Quality Supervision and Inspection and Quarantine) signed a cooperation agreement for the mutual recognition of measurement results for weighing instruments.

PTB – A Provider of Metrological Services and a Partner of Industry, Science and Society

Roman Schwartz, Harald Bosse

The basic prerequisite for a modern industrialized country is the existence of an efficient metrological infrastructure. For this purpose, each industrialized country maintains a national metrology institute. In Germany, the national metrology institute is the "PTB". PTB's specific mandate, assigned to it by the State, is to provide an internationally accepted and efficient metrological infrastructure for industry and trade, as well as for science and society. But it is also of great importance that the consumers, the entrepreneurs and the authorities can trust in reliable and impartial measurements.

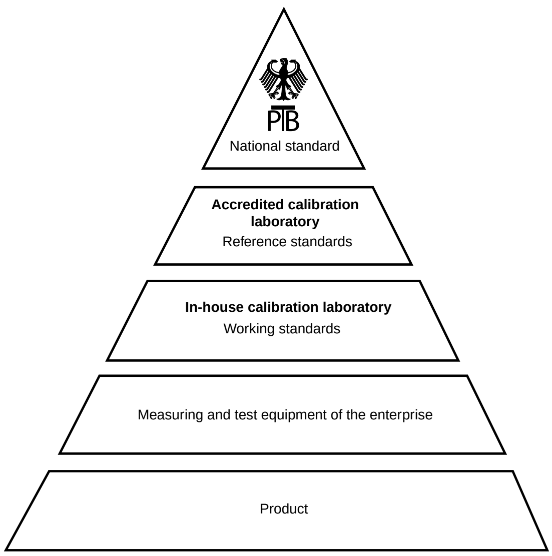
Part of this mandate, which is now 125 years old and has hardly changed over time, is to provide a large variety of those scientific services PTB accounts for – often in cooperation with other national metrology institutes, with universities and research institutions, and with partners from industry. For an export-oriented national economy such as that of the Federal Republic of Germany, the existence of an advanced metrological infrastructure, as well as the availability of metrological know-how at the highest levels, is indispensable for the development of new technologies – and also the international acceptance of the certificates that are based on measurements and tests.

PTB's research in the field of metrology – in close cooperation with industry and other research institutions – not only provides the basis for realizing the measurement units and the corresponding scales, but it is also the precondition for accurate and reliable measurements and tests for both industry and trade. Modern production processes require adequate, high-level measuring techniques to meet the expectations of manufacturers and users of the products. This is a precondition for high-quality end products and well-functioning quality systems in industry. For this purpose, all relevant measurement results have to be traceable to the International System of Units (SI), as is required by all national and international standards.

PTB's tasks, according to its statutes, are calibrations, tests and certifications according to the Units and Time Act [last modified by Article 1 of the Law of 3 July 2008 (Federal Law Gazette I, p. 1185)] as well as according to the Verification Act [last modified by Article 1 of the Law of 7 March 2011 (Federal Law Gazette I, p. 338)]. These tasks are part of the traditional metrological services provided to the economy. Also research & development cooperations – in the broadest sense of the term – with industry are understood as "services". Over the past few years, such projects have strongly increased, especially in cooperation with small and medium-sized enterprises (SMEs), which is supported, in the field of metrology, by special programmes of the Federal Government.

Calibrations are of great economic importance for industry – not only in the production process, but also as a sales argument. To cover the increasing need for calibrations, the *Deutscher Kalibrierdienst (German Calibration Service* – DKD) was established in 1977 whose accreditation body was transferred into the new *Deutsche Akkreditierungsstelle GmbH* (DAkkS) on 17 December 2009. The traceability of the standards of accredited calibration laboratories (which are mostly private ones) to the standards of PTB is organized in a hierarchical way so that the uniformity of the weights and measures is ensured and the measurement uncertainty is taken into account. To calibrate the reference standards of the accredited laboratories, which is done at regular intervals, the traditional areas of metrology – mechanical measurands such as mass, force, torque, pressure, acceleration, flowrate (gas and fluids), but also acoustic, electric, optical, thermal and dimensional measurands – play the most important role. All measurement capabilities used for this purpose are part of PTB's quality management system (QMS), which is internationally recognized and meets the requirements laid down in ISO/IEC 17025 as well as the principles stated in ISO 9001:2000.

Besides calibrations, PTB's range of services also includes conformity assessments, i. e. tests, type approvals and certifications of measuring instruments and measuring systems which are based on



Picture on the left: "Traceability pyramid" of product calibrations to the standards of PTB

Picture on the right: Monitoring speed in road traffic numerous national and European directives and regulations, for instance, the Measuring Instruments Directive (MID) that came into force in 2006. These activities are coordinated by PTB's certification body, which was created on 1 October 2008 and which covers not only all categories of measuring instruments pursuant to the MID, but also non-automatic weighing instruments and the field of explosion protection. Another service offered to manufacturers by the certification body is the assessment of their quality management system. Every year, PTB issues approx. 2500 certificates, covering around 30 different categories of measuring instruments.

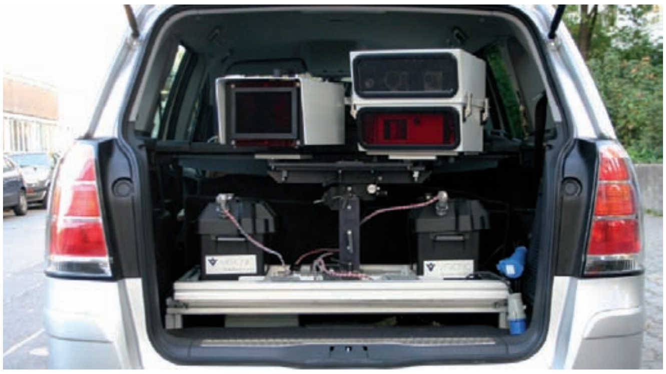
Last but not least, German industry benefits from the fact that employees from PTB are represented in more than 1000 national and international committees where they share their metrological expertise. In the main, these committees are standardization organizations, metrological organizations, specialized committees, organizations for the harmonization of provisions and test procedures, federal and state ministries, authorities, offices, employers liability insurance associations and professional associations.

The basis for conducting calibrations and tests at the highest international level is fundamental research in the field of metrology. Fundamental research is, therefore, anchored as a task of PTB in its statutes and is often performed in cooperation with universities, non-academic research institutions and other national metrology institutes.

The task of fundamental research in metrology is to find new and enhanced methods for the realization and dissemination of the legal units. A particular challenge is the current work on the traceability of SI units to fundamental constants. This has already been achieved for the second and the metre. For the ampere, the kelvin, the kilogram and the mole, these worldwide activities are still underway. The main aim is to determine with great accuracy the numerical values of the fundamental constants used. PTB significantly contributes to these activities through highly sophisticated experiments, especially for the determination of the Avogadro constant and of the Boltzmann constant. The international Avogadro Project, which has been running for several years already, is led by PTB and is aimed at determining the number of atoms contained in a nearly perfect silicon sphere with great accuracy. Together with the watt balance experiments, in which the weight of a mass is compensated by an electromagnetic force, it is supposed to contribute to the re-definition of the kilogram.

Within the scope of the European Metrology Research Programme (EMRP), not only fundamental metrological research is conducted. The EMRP also deals with the so-called "grand challenges" *"Energy"*, *"Environment"* and *"Health"* and carries out metrological research & development projects in cooperation with the European metrology institutes and with partners from science and industry.

Correct, trustworthy and reliable measurement results are an important basis for fair trade, for the safeguarding of the public interest, and for people having confidence in official measurements. It is here where legal metrology comes in. Legal metrology protects the consumer when purchasing goods or making use of services that can be measured. In commercial exchanges, legal metrology ensures correct measurement results, which is in the interest of fair trade; it serves legal security and enhances people's confidence in official measurements, for example in traffic surveillance, and it makes sure that legal limiting values are observed, e. g. in health protection, in occupational health and safety, and in environmental and radiation protection. In this field, the activities of PTB are not only based on national regulations and directives, but increasingly also on European and international ones such as, e. g., the European Measuring Instruments Directive (MID) mentioned above and the recommendations of the International Organization of Legal Metrology (OIML).



One of PTB's services is especially well-known: the realization and dissemination of legal time in Germany – and beyond. PTB operates four primary caesium clocks, the so-called "atomic clocks", which enable the realization of the unit of time (the second). By means of these, legal time is disseminated to the population and to users from industry, economy and research via the long-wave transmitter DCF77, but also via the Internet, via a telephone service hotline and via satellite links. The DCF77 transmitter is operated in Mainflingen near Frankfurt (Main); its reach is more than 1500 km, thus covering all European countries.

Another important service provided by PTB is technology transfer. Technology transfer encompasses all those activities which are linked with the economic exploitation of the results obtained by PTB. Right from the start, one of the main aims has been to further Germany's economic growth by developing modern measurement technologies which are closely interlinked with industry. The aim of technology transfer is to promote the cooperation with industry, to take out patents, and to raise the awareness of PTB employees for the fact that their results can be exploited for industrial purposes. This is another way for PTB to safeguard the competitiveness of German and European industry. Meanwhile, PTB has filed and been granted more than 100 patents – some of them being European or US patents. PTB presents its research & development results regularly at specialized trade fairs so as to reach interested circles and potential licencees.

Two examples of successful technology transfer measures can be given here: first of all, novel neutron dosimeters – of which more than 1000 pieces have already been produced and sold under licence by a European-American consortium – and a successful spin-off of PTB scientists in the field of optical coordinate measuring technology using laser tracers. ■

2002 – Evaluation of the PTB by an international commission

On behalf of the Federal Ministry for Economics and Labour, PTB was – for the first time – subjected to an evaluation by a commission, which was composed of representatives from important metrological institutions of other nations, as well as by German large-scale research institutes, German universities and German industry. In summary, the professional competence and the quality of the work were considered to be excellent. The equipment was generally considered to be very good, partially, however, with a clear need for investments.

2002 – Hydrodynamic Test Field

In 2002, one of the worldwide largest and most accurate facilities for the measurement of the volume and flowrate of liquids was put into operation. With this facility, all fluid measurements carried out in Germany – whether by means of water, mineral oil or other meters – are traced back to a national standard. At the same time, an important contribution is made to the international uniformity of liquid measurements.

2003 – Inauguration of the Albert Einstein Building

In 2003, PTB inaugurated a new building for optics – the Albert Einstein Building. It replaced the Kösters Building, which had been set up before World War II.

2004 – Metrological scanning probe microscope with a large measurement range

Among other things, a probe-microscopic measuring head developed at PTB was integrated into a commercial positioning machine. In this way, a metrological scanning probe microscope with a large measurement range of 25 mm × 25 mm × 5 mm is yielded, for various applications in micro- and nanometrology.

2004 – 3D auto-tracking laser interferometer (laser tracer)

The development of an auto-tracking laser interferometer – together with novel multilateration procedures – led to a clear reduction of the measurement uncertainty for the calibration of 3D coordinate measuring machines. Based on this technology, the new company "Etalon" was founded as a spin-off on PTB's site in Braunschweig.

2004 – 304-channel SQUID system

In 2004, the BMSR II (see page 55) received an adequate measuring system, consisting of 304 SQUID magnetometers which – due to their special configuration – permit the mapping of biomagnetic vector fields. Compared to EEG measurements by means of electrodes – which only detect scalar measurands – this is an essential advantage and helps to improve the solution of the inverse problem of the reconstruction of the neuronal signal paths.

2002

2005 – Nobel Prize in physics awarded to Theodor Hänsch

Theodor Hänsch (born on 30 October 1941 in Heidelberg), director of the *Max Planck Institute for Quantum Optics* in Garching, is regarded as a pioneer of laser spectroscopy. Together with John Lewis Hall and Roy J. Glauber, he was awarded the Nobel Prize in physics for the development of the frequency comb and his contributions to laser spectroscopy. The frequency comb proved to be the precision tool for frequency and time measurement. Since 1999, Theodor Hänsch is Member of the PTB-Kuratorium. Since 1999, Theodor Hänsch has been a member of the PTB Kuratorium.

2005 – Dismantling of reactor completed

In 2005, the reactor building was released from the supervision specified under the Atomic Energy Act and can now be used for other purposes.

2006 – SINIS voltage standard for 10 V

In 2006, a first worldwide programmable 10-volt Josephson voltage standard in SINIS technology for tracing electrical AC quantities directly back to fundamental constants was completed. On this basis, PTB developed programmable 10-volt Josephson standards in SNS technology in 2010. This technology is more robust and promises higher production yields.

2008 – Richard Glocker Building with new electron accelerators

On 11 July 2008, the president of PTB, Prof. Göbel, and State Secretary Jochen Homann from the Federal Ministry of Economics and Technology officially dedicated the Richard Glocker Building. This building accommodates two medical electron accelerators for dosimetry in radiotherapy and a research accelerator which is unique worldwide. Besides the standards of the unit "gray" and dosimeter testing, the focus of the investigations is on dosimetric fundamental research, especially on the interaction of radiation with various materials, including biological systems.

2008 – The MLS at the Willy Wien Laboratory

In April 2008, the user operation of PTB's own low-energy electron storage ring Metrology Light Source (MLS), which was set up at the Willy Wien Laboratory close to BESSY II in Berlin-Adlershof in collaboration with the *Helmholtz Zentrum Berlin ("Helmholtz Centre Berlin"* – HZB), was begun. The MLS is the primary source standard for radiation from the near infrared into the range of soft X-rays.

2008

2007 – Foundation of EURAMET

On 11 January 2007, EURAMET (European Association of National Metrology Institutes) was founded at PTB's Berlin Institute as a registered association domiciled in Braunschweig according to German legislation. It replaced EUROMET. On 1 July 2007, EURAMET took up its work as Europe's Regional Metrology Organization (RMO) and was officially recognized by the BIPM as the successor organization to EUROMET within the scope of the CIPM MRA.

2008 – Evaluation of the PTB by the *Wissenschaftsrat (German Council of Science and Humanities)*

Within the scope of the evaluation of the departmental research institutes initiated by the Federal Government, PTB, too, was subjected to an evaluation, with excellent results. In its report, the *Wissenschaftsrat (German Council of Science and Humanities)* wrote that "PTB convincingly does justice to its role as one of the worldwide leading metrological establishments" and attests that "the European activities of PTB are exemplary for other federal institutions with R&D responsibilities".

2008 – The Units and Time Act

The *Act on Units in Metrology and the Determination of Time* dated 3 July 2008 pools all legally relevant aspects concerning the physical units as well as PTB's competencies for their realization and dissemination. This new act reflects PTB's real tasks as a national metrology institute: research and development as well as the transfer of knowledge and technology are explicitly pointed out as being parts of PTB's mandate.

2008 – Density of ultra-pure water

Water is available worldwide and can be produced in an ultra-pure state. In 2008, PTB succeeded in measuring its density with a magnetic floatation balance made specifically for this purpose. This balance performs the measurements with a relative uncertainty of $< 2 \cdot 10^{-6}$ over a temperature range from 0 °C to 90 °C. This is the pre-condition for the broad utilization of water as a reference liquid.

2009 – First Bose-Einstein condensate from ^{40}Ca

The first Bose-Einstein condensate with ^{40}Ca was generated at PTB from an earth alkali element. In contrast to the Bose-Einstein condensates from alkali elements, which are used most frequently, earth alkali elements, in connection with their ultra-narrow optical transitions, open up novel possibilities for measuring frequency with high precision.

2010 – A standard to determine proteins

In 2010, PTB and the Ludwig Maximilians University of Munich developed a primary method to measure clinical protein markers. The human growth hormone, which also plays a role in doping, is measured as a model substance. The analytical reliability and accuracy of this method are based on the application of isotope dilution mass spectrometry (IDMS). For the first time, a protein analysis procedure has thus been recognized internationally as a national standard.

2010 – New value for the Avogadro constant from ^{28}Si

Within the scope of the international Avogadro Project coordinated by PTB, the Avogadro constant N_A was measured in 2010 using a sphere consisting of a highly enriched ^{28}Si single crystal. With this sphere, a relative uncertainty of $3 \cdot 10^{-8}$ can be attained – better than ever before. The value of $6.02214082(18) \cdot 10^{23}$ mol^{-1} obtained in this way is a milestone on the way to the redefinition of the kilogram on the basis of a fundamental constant whose numerical value has been defined.

2008

2009 – PTB joins the OIML MAA

After joining the OIML MAA, PTB certificates for non-automatic weighing instruments and load cells now have to be accepted worldwide. Pursuant to the Mutual *Acceptance Arrangement of the International Organization of Legal Metrology* (OIML MAA), PTB belongs to the group of 10 institutions worldwide which can issue certificates which are not only "binding in honour", but also internationally legally binding.

2009 – Part of the *Deutscher Kalibrierdienst* (DKD) becomes "DAkkS"

Due to European regulations, it had become necessary to establish the *German Accreditation Body (Deutsche Akkreditierungsstelle* – DAkkS) on 7 August 2009; the DKD hereby ceded its accreditation activities. The new foundation of the DKD as PTB's regulatory committee took place on 3 May 2011.

2009 – Master plan for the "Berlin Institute"

On the initiative of the *Bundesbauverwaltung (Federal Building Authority)*, a master plan was drawn up in 2009 to turn the buildings in Berlin-Charlottenburg into a uniform campus. On 9 November 2009, this master plan was handed over to the Presidential Board on the occasion of a public presentation in front of representatives from the German government, the State of Berlin and the district of Charlottenburg-Wilmersdorf.

2010 – The unit of capacitance "farad" is based on the quantum Hall effect

In 2010, PTB demonstrated a new procedure for reproducing the unit of capacitance on the basis of the alternating current quantum Hall effect. With this quantum-metrology approach, a relative uncertainty of 10^{-8} can be attained – which represents a considerable improvement compared to the traditional procedures based on calculable capacitors.

2010 – "Live Cell Imaging" with ions

The method of "Live Cell Imaging" was established at the micro-ion beam. Live cells react to radiation-induced double strand breaks of the DNA by means of diverse processes – from detecting the damage to repairing it. Some of these processes take place within seconds; this can be observed optically by the fluorescent marking of proteins.

2010 – Industrial computer tomography facility

The measurement procedures and artefacts developed with this facility made the traceable dimensional measurement of outer and inner structures of 3D objects possible for the first time. Fields of application of this research work are dimensional metrology and medical engineering.

2011 – Boltzmann constant redetermined

Whilst carrying out measurements to determine the Boltzmann constant k – which is the precondition for the new definition of the kelvin – with great precision, PTB succeeded in demonstrating that with an uncertainty of $8 \cdot 10^{-6}$ at present, the dielectric-constant gas thermometer is, besides acoustic gas thermometry, well suited as an independent procedure at the highest level. Its uncertainty is expected to decrease down to $2 \cdot 10^{-6}$ within the next two years.

2011 – Reference wall for laser trackers

In the building of the former research reactor, a reference wall was put into operation which makes it possible to investigate and verify laser trackers and photogrammetric 3D measuring systems with high accuracy.

2012

2012 – Joachim Ullrich becomes President of the PTB

Joachim Hermann Ullrich (born in 1956 in Edenkoben, Rhineland-Palatinate) studied Geophysics and Physics at the *Universität Frankfurt (Frankfurt University)*, where he also received his doctorate and qualified as a professor. Following scientific work in Darmstadt at the *Gesellschaft für Schwerionenforschung* and in the United States at Kansas State University as well as at the University of Missouri, he was offered the chair of Experimental Physics at the *Universität Freiburg (University of Freiburg)* in 1997. In 2001 Ullrich was appointed as a Director of the *Max-Planck-Institut für Kernphysik (Max Planck Institute for Nuclear Physics* – MPIK) in Heidelberg. His scientific focal points are atomic, molecular and laser physics as well as precision spectroscopy. Among the most important honours he has received are the Leibniz Prize of the *Deutsche Forschungsgemeinschaft (German Research Foundation)* awarded in 1999 and the Philip Morris Research Award received in 2006. From 1 January 2012 Ullrich has taken on the post of heading PTB. He is the 14th president in the 125-year history of PTB.

PTB at the Beginning of the 21st Century

Ernst O. Göbel
Jens Simon

Metrology – the scientific basis of measurement and of all applications derived from it – rather lives a shadowy existence among the sciences. Whereas in the ancient world, metrology was so important that non-observance of metrological laws – e. g. during the construction of the Egyptian pyramids – was punished with death, today the use of precise and internationally uniform metrology is a matter of course: everyone uses metrology, but scarcely anyone knows it.

As no scientific experiment, no industrial process and no trade of goods and merchandise can do without quantification – i. e. without measurement technology – metrology is so omnipresent that it almost becomes invisible. It only attracts attention when it does not – or not correctly – work anymore. For this reason, the mandate for a national metrology institute – such as the Physikalisch-Technische Bundesanstalt – is to ensure a continuously functioning and, consequently, a reliable and progressive metrological infrastructure which meets both the highest requirements of science and high-technology industry and the marginal conditions of legal metrology in everyday life. All these facets are combined under the umbrella of PTB. This makes it all the more difficult to get a simple and uniform idea of the metrology institute "PTB". To remain with the picture – PTB acts on several stages, and that in quite different roles. Only the synopsis of all these roles shows the true character of PTB.

Worldwide Metrology and the Metre Convention

The idea of creating uniform measures for everyone – independent of sovereign specifications – was born already in the time of the French Revolution. The metre as the 40 millionth part of the Earth's meridian ("metre prototype") and the kilogram as the mass of a cube of pure distilled water with an edge length of one decimetre ("kilogram prototype") were the first definitions of such metric measures. This metric system obtained, however, a contractual basis only in 1875 – and then at once a global one. In view of the emerging rapid development of industrialization and the exchange of goods, metrology could not possibly stop at national borders. At that time, 17 nations, among them the German Empire, signed the *International Convention of Weights and Measures*. Only 12 years later, the *Physikalisch-Technische Reichsanstalt (Imperial Physical Technical Institute* – PTR) was founded in Berlin as the first – today we would say – major research institution and as the first national metrology institute worldwide. Today, 55 nations are members of the *International Organization of Weights and Measures* (abbreviated: *Metre Convention*), and a further 33 countries are associated. The member states commit themselves to use uniform measures and weights which are today defined by the International System of Units (SI). For the Federal Republic of Germany, PTB is responsible for the active cooperation in the Metre Convention. With respect to the committees, the Federal Republic of Germany has – in addition to the USA, Japan and France – a permanent seat in the Comité International des Poids et Mesures (CIPM) which is held by the president of PTB.

In view of the aim of establishing a worldwide uniform system of measures, the signing of a treaty (Metre Convention) was only an important first step. In practical applications, worldwide uniformity is achieved only by concrete cooperations, a great number of confidence-building measures and transparent measurement results. For this reason, PTB cooperates with the other national metrology institutes (NMIs) in a large number of joint research and development projects and is – at the international level as well as at the European level (as already described) – incorporated into the metrological structures as an important partner: from the Metre Convention and the "Organisation Internationale de Métrologie Légale (OIML)" to the "European Association of National Metrology Institutes (EURAMET)" and the "Western European Legal Metrology Cooperation (WELMEC)". The central element to achieving a worldwide uniform and harmonized metrology and to remove, at the same time, technical barriers to trade between the states, are international comparison measurements between the national metrology institutes. This allows the degree of harmonization of the national standards and of the calibration and measurement capabilities of the individual states to be determined quantitatively. The results of these comparison measurements, which are carried out at the highest level, are stored in a data base. They are accessible to the public and part of the quality assessment and quality assurance of the institutions involved. As PTB has special laboratories for almost all relevant physical quantities, the number of comparison measurements in which PTB participates is very high (between 50 and 100 per year).

The International System of Units, the SI, is based on the intention to trace the fundamental phenomena of the physical world – time, length, mass, temperature, current …– back to a uniform reference system. In spite of this revolutionary idea

200 years ago, the seven base units still suffer some definitory insufficiencies today, which is reflected by the changes in the kilogram prototype in the safe of the BIPM in Paris. The challenge is to place the base units on a solid and permanent basis, as has already been successfully accomplished for the second and the metre with reference to atomic excitations and the speed of light. PTB is decisively involved in this current restructuring of the system of units: for example with the Avogadro project for the redefinition of the kilogram and the mole, with the "Boltzmann constant" project for the redefinition of the kelvin, and with the experiment to trace the ampere back to the elementary charge of the electron. As soon as the required experiments will have achieved sufficiently small uncertainties and be consistent with one another, the General Conference of the Metre Convention (CGPM) will adopt the new definitions, determine exact numerical values for the fundamental constants involved and establish the "new SI".

Permanent Revision – for International Recognition

To have quality is one thing. To document quality – and to make it visible to and credible for third parties – is quite a different thing. According to the international corpus of technical rules, this is achieved by means of a quality management system. Such a quality management system has become indispensable for the international recognition of one's own services. For PTB, with its broad spectrum of tasks, the quality management system comprises all interlinked business areas: fundamentals of metrology, metrology for economy, metrology for society, and international affairs. PTB's quality management system meets all legal requirements as well as the requirements of DIN EN ISO/IEC 17025 and, thereby, also the principles of DIN EN ISO 9001. In all these fields of activity, PTB also meets the requirements of the *"Recommendations of the Deutsche Forschungsgemeinschaft zur Sicherung guter wissenschaftlicher Praxis (German Research Community for the Safeguarding of Good Scientific Practice)"*. In addition, the requirements of ISO Guide 34 are fulfilled for reference materials in the field of chemistry. PTB meets the requirements for conformity assessment bodies and is notified body 0102 in accordance with European directives. All these requirements are the basis of an internal self-assessment process whose aim it is to permanently improve and maintain the high quality of PTB's services. The permanent evaluation of the current spectrum of tasks and the orientation towards future questions is realized with the aid of the "Kuratorium" (Advisory Board) of PTB. Since 2004, annual assessments have, in addition, been performed within the scope of a European project between the German-speaking NMIs. Compliance with the quality requirements is documented by a public declaration of the president of PTB. The current version of this declaration is published on the Internet. It is based on the exchange of research results, international comparison measurements, the disclosure of results and measurement capabilities and the annual assessment of the quality management by international technical experts within the scope of the Metre Convention and OIML.

PTB's responsibility relates not only to the last measurable digits behind the comma and the international comparison of these results. PTB also promotes projects for the establishment of a quality infrastructure (QI) in many development countries and in countries in transition within the scope of the German Development Cooperation, in order to help the local industry to establish the required metrological infrastructure. In the 1960s, technology transfer and the establishment of metrological partner organizations was started. Today, the cooperation mainly relates to the establishment and development of the quality infrastructure in the partner countries as well as to offers addressed to the users for making use of the QI services. The Technical Cooperation Department (TC) of PTB is integrated into the development policy of the Federal Government and makes its contributions to the fight against poverty within the scope of the focal point "sustainable economic development". PTB advises partner governments and ministries, promotes the institutions of the quality infrastructure and also supports small and medium-sized enterprises. This work is very appreciated worldwide, which is meanwhile reflected by a great number of current cooperations with former partner countries at the highest metrological level and for the benefit of both sides. Partner countries of the initial years such as China, India, South Korea, Brazil, Argentina, Mexico, and later also Kenya and South Africa, today represent their interests independently in the respective international technical organizations.

Joint Metrology Research in Europe

"Classical metrology", which has so far been geared to physical measurement technology, permanently faces the task of extending the measurement ranges and of reducing the measurement uncertainties. For some time, however, also metrological contributions to the solution of the great challenges of our time, which are defined by terms such as health, energy, environment, safety and mobility, have become important to the degree to which exact quantification is required. Therefore, other disciplines – such as chemistry, biotechnology and medicine – are, in this context, knocking on the doors of metrology. One single national metrology institute alone cannot deal with the amount of these tasks. For this reason, most of the European metrology institutes have committed themselves to cooperate in their research and development work. For that purpose, a European Metrology Research Program (EMRP), half of which is funded by the European Commission, was elaborated to serve as a basis for the next few years. As the largest metrology institute in Europe, PTB shoulders – in accordance with its research budget – almost 40 % of the funds to be raised. Here, too, the tendency is clear. Metrology research, which was formerly mainly national, becomes European.

PTB in the German Research Landscape – Departmental Research

Formally, PTB is one of those research institutions which are assigned to individual federal ministries – in the case of PTB to the Federal Ministry of Economics and Technology – and not to the Federal Ministry of

Education and Research like the large research organizations. Whereas many of these institutions of the so-called "departmental research" have a strongly regulatory character, PTB understands itself in the first instance as a research institute with a corresponding degree of autonomy and scientific freedom. From the very beginning, PTB has not been a "classical authority" but a research institution with a sovereign service task, which has today been established in a total of 23 laws and ordinances. PTB's research work is derived from the requirements of a worldwide leading metrology and is, therefore, not purely fundamental research, even if it faces the challenges at the frontline of research. Its research projects often cover far longer periods of time than university projects (as shown by the "Avogadro project", which has a duration of more than two decades). Its special approach, which is aimed at metrological precision, makes PTB a partner sought after for the most different cooperation projects with universities and non-university research institutions with participations in special research fields and excellence clusters. Due to its metrological competence, PTB occupies a central position in the German research landscape. It can, however, only meet the high expectations if policy grants it the same framework conditions.

Calibrations at the Highest Level – Partner of Industry

The German Units and Time Act explicitly assigns two tasks to PTB: the realization and the dissemination of the physical units. To realize such a unit means to operate, to maintain and to develop a national standard for the unit in question (or, if required, national standards for the whole scale of this unit) according to the state of science. This task as a "guardian of the units" is necessarily complemented by the dissemination of the units to the customers in industry and society by suitable "bridges from this island of highest accuracy to the worlds of application". This is achieved by calibration, i. e. by metrologically comparing the devices of the customers with the PTB standards. PTB works in accordance with a principle of subsidiarity and cedes the calibration to an external laboratory, provided that this laboratory can meet the requirements in the same way as PTB. For that reason, only industrial enterprises from high technology branches, on the one hand, contact PTB with special calibration requests and, on the other hand, in particular accredited calibration laboratories which must – in accordance with the quality management provisions – submit their own reference standards for calibration at regular intervals. The several thousand calibrations which PTB carries out every year thus provide the basis for several millions of calibrations in Germany as a highly industrialized country, which contributes considerably to the economic value creation in Germany. The German economy benefits from the internationally renowned image of PTB, as a certificate of PTB represents a significant competitive advantage on the market. PTB certificates enjoy worldwide confidence and are recognized in almost all countries.

Protection Function – for Man and the Environment

Modern metrology is required to extend the knowledge at the front of science, as a highly specialized production aid in the high-technology industry and as a reliable accounting mechanism in economy and trade. But also a society – especially a highly technical one – must be made aware of the risks in which it lives, and these risks must be illustrated by concrete measurement values. If the facts are known, harmful consequences can possibly be avoided. How high is the current radiation burden of the environment by natural and artificial radioactivity? Which substances do we blow – and in what concentration – into the air from exhausts and factory chimneys? Which measures can we take to confine the noise in our working environment and in our world of mobility? How can explosions in chemical production plants, gas pipelines or in other ignition-capable atmospheres be avoided or confined? Our society needs reliable answers to questions of this kind. Correct measurements are the prerequisite for the quantification of these risks. In Germany, PTB provides the metrological basis also for the surveillance of the environment and the protection of the citizens, for example, with its trace survey station for radioactive substances in the air, with the type examinations of exhaust meters and their chemical analysis, with its standards for sound and ultrasound measurements, or with its know-how in physical safety technology and explosion protection. Here, reliable metrology is a means of objectification and helps to take decisions in our risk society.

PTB's Perception in Braunschweig and Berlin

Two sites, two histories, two faces, one institution. First of all there is Berlin, the traditional site of PTB. In today's Charlottenburg-Wilmersdorf district, the Physikalisch-Technische Reichsanstalt (PTR) was founded on grounds which Werner von Siemens donated to the German Empire, in the immediate vicinity of the Technical University. For more than 50 years, the PTR was concentrated at this location. Then came the Third Reich, the war, the destructions and, after the end of the war, the liquidation of the PTR in the two German states. In 1946, the parts of the PTR which had been removed to Weida in Thuringia were converted into a *"Deutsches Amt für Maß und Gewicht" (German Agency of Weights and Measures)*. In 1953, the PTR on the traditional grounds in Charlottenburg was affiliated as "Berlin Institute" to the PTB, which was meanwhile domiciled in Braunschweig. Today, the Berlin site of PTB is closely interlinked with the scientific landscape in Berlin. A great number of scientific cooperations exist with the Technical University – not only due to the spatial contiguity – and also with the Humboldt University. In medical physics, in particular the cooperations with the medical centres and the university hospitals (for example, in Berlin-Buch and in Berlin-Steglitz) should be mentioned, and for physics with synchrotron radiation, at the scientific and economic site Adlershof, an own storage ring (the "Metrology Light Source") and the laboratory at the storage ring Bessy II of the Helmholtz Centre in Berlin. Whereas in Berlin, PTB is a small institution in a large scientific landscape which is well-established in circles of experts, the situation of PTB is quite different at its headquarters in Braunschweig. In the research region Braunschweig, PTB is – in addition to the Technical University, with which a great number of cooperations are maintained – the largest research institution and, due to its magnitude, much more present in the public awareness, in particular due to one physical quantity: time. The reputation of PTB in Braunschweig is, to a great extent, based on its atomic clocks which – unjustifiably – eclipse its other top performances, because "time is made in Braunschweig". PTB thus ranks among the most prominent landmarks of the city. In this situation, two things are unimaginable: PTB without Berlin, and Braunschweig without PTB.

A Glimpse into the Future

As long as the constitution of the Federal Republic of Germany endures, the state bears the responsibility for both the maintenance and the uniformity in metrology which is stipulated in article 73. From this fact, the manifold legal tasks of PTB are derived. To cope with these tasks now – and still in 25 years – in accordance with the increasing requirements of economy, science and society, research and development work must be carried out at the frontline. Consequently, the mandate of PTB will remain. The environment, the framework conditions, the focal points of work, the organizational structure and the legal status may change. The formal "corset" of an authority, as it is currently valid for the institutions of strategic research, might become too narrow for the tasks of PTB in the long run. The assignment to the Ministry of Economics and Technology (BMWi) is reasonable and suggests itself due to the industry-oriented activity of PTB. PTB places high-quality advisory skills in technical and scientific matters at the disposal of the BMWi.

In the age of globalization, the international responsibility and activity of PTB will increase. With its great commitment and its decisive contributions to international metrology projects, PTB is trendsetting also in this context. Unified Europe remains one of the great challenges of the next few years and decades – not only politically and economically, but also in view of metrology. The withdrawal to a national alternative is not conceivable.

If PTB did not exist, one would have to invent it. Not only have all industrialized states of today followed the example of the German Empire of 125 years ago and established metrological institutions like the PTR. The same applies – as can be seen – to today's developing countries and countries in transition. Metrology and its institutional protagonists will – also in future – belong to the infrastructural backbone for economy, science and society. The subject fields will become broader and the resulting challenges interdisciplinary. ■

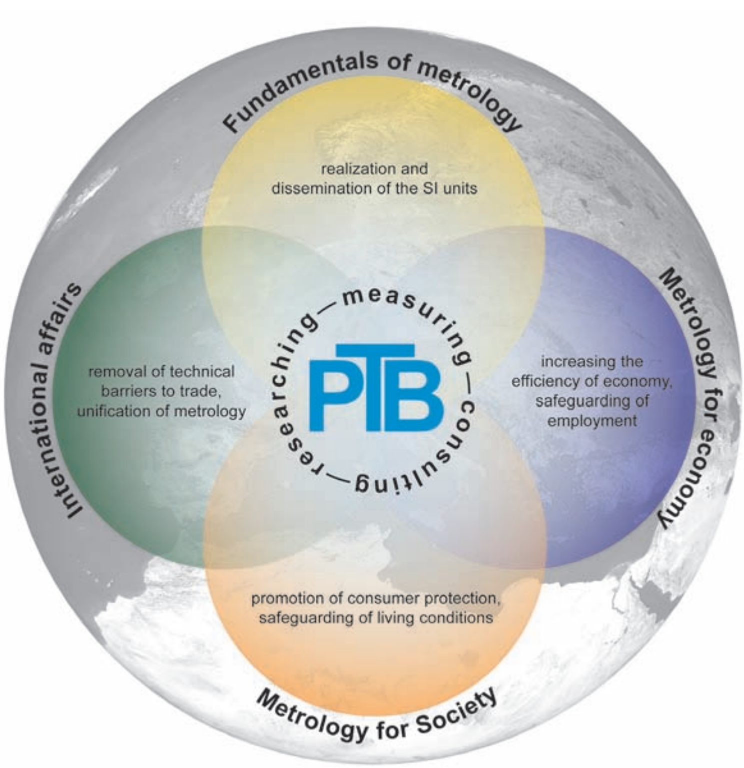


Figure:
The tasks of PTB can be divided into four fields of activity: fundamentals of metrology, metrology for economy, metrology for society, and international affairs.

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We would like to give our heartfelt thanks to all the authors, all the current and past employees of PTB named, as well as all those who we may have forgotten to mention here for their help in realizing this journal!

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Monographs on the history of the PTR/PTB

The following monographs are the source of diverse information which is printed here. They are therefore strongly recommended to readers who would like a deeper insight into metrology in Germany.

David Cahan:
"Meister der Messung – Die Physikalisch-Technische Reichsanstalt im Deutschen Kaiserreich"
(VCH Verlagsgesellschaft mbH, Weinheim 1992)*

Ulrich Kern:
"Forschung und Präzisionsmessung – Die Physikalisch-Technische Reichsanstalt zwischen 1918 und 1948"
(VCH Verlagsgesellschaft mbH, Weinheim, 1994)*

Dieter Kind:
"Herausforderung Metrologie – Die Physikalisch-Technische Bundesanstalt und die Entwicklung seit 1945"
Wirtschaftsverlag NW, Verlag für neue Wissenschaft, Bremerhaven, 2011 (1. Auflage: Bremerhaven, 2002)

Rudolf Huebener, Heinz Lübbig:
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Vieweg+Teubner Verlag, Springer Fachmedienverlag, Wiesbaden GmbH, 2011

J. Bortfeldt, W. Hauser, H. Rechenberg:
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Helmut Rechenberg:
"Hermann von Helmholtz. Bilder seines Lebens und Wirkens"
(VCH Verlagsgesellschaft mbH, Weinheim, 1994)*

*These books were re-published in 2011 by Wirtschaftsverlag NW, Verlag für neue Wissenschaft, Bremerhaven