Direct measurements of extreme temperatures

Project SIB01
Implementing the new kelvin

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A new way to measure temperature

The SI unit of temperature – the kelvin – is to be redefined in terms of the Boltzmann constant, which relates energy at the individual particle level with temperature. This redefinition, along with other recent advances in temperature metrology, will enable a fundamental change in the way we measure temperature.

Current temperature scales rely upon a set of fixed points determined by primary thermometry. This project will improve primary thermometry at temperatures ranging from 0.0009 K to over 3000 K and will assign definitive thermodynamic temperatures to a set of high temperature fixed points for the first time. This, along with new sensing methods and techniques, will allow extreme temperature measurements to be linked to a direct realisation of the kelvin.

The results will benefit the large number of industries that measure temperature on a daily basis, in particular low temperature industries such as cryogenics and high temperature industries such as steel production.

Comparing clocks across Europe

Project SIB02
Accurate time/frequency comparison and dissemination through optical telecommunication networks

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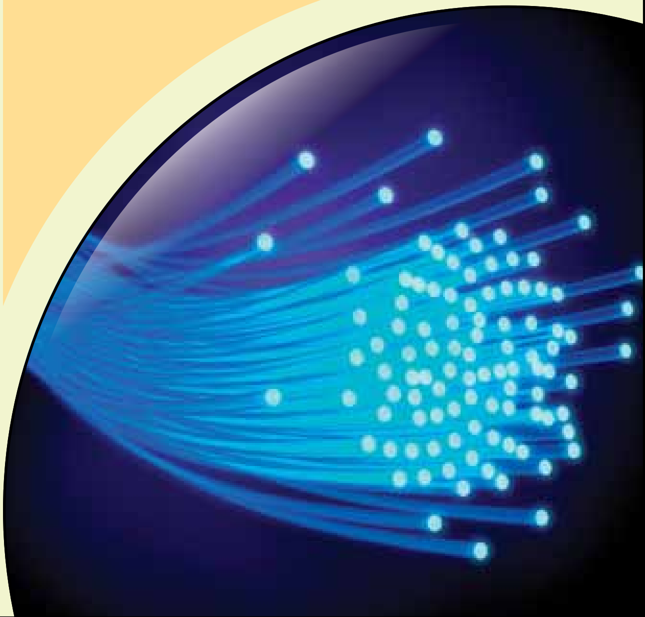
Using fibre rather than satellites

Optical atomic clocks could be used to redefine the second as they are more accurate than the microwave atomic clocks used today. However, the only way to check the performance of these optical atomic clocks is by comparing them with other atomic clocks, and the current satellite-based techniques for doing this are simply not accurate enough.

This project will investigate techniques for comparing remote optical clocks, separated by distances of up to 1500 km. The project will study the fundamental limitations of optical fibre links and aims to reduce the contribution of these links to the uncertainty of the frequency calibration.

As well as contributing to a redefinition of the second and fundamental physics experiments, the dissemination of atomic time through optical fibres could also provide a backup for GPS timing in power grids and mobile telecommunications networks.



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EURAMET
European Association of National Metrology Institutes

European Metrology Research Programme

SI Broader Scope

An overview of the funded projects from the Targeted Programme SI Broader Scope.

The aim of these projects is to underpin the development of the SI system of measurement units.

The projects focus on preparations for the implementation of the redefinition of the kilogram and support developments of practical realisations of the redefined base units and affected derived units.

The SI system is not static but evolves to match the world's increasingly demanding requirements for measurement.

Measurements are made constantly in industry, healthcare, environmental monitoring and everyday life. The SI system of internationally agreed units underpins these measurements, giving us traceability and associated confidence in measurement consistency across the world. Since the units were first introduced, advances in science and technology have led to revisions to their definitions. Currently all of the units but one, the kilogram, are defined with respect to fundamental constants of nature, meaning that these units can be realised anywhere in the world and are not tied to any one artefact.

Now it is also time to redefine the kilogram in terms of fundamental constants, and to update the definitions of the other units so that they are the most accurate that modern science allows.

The seven SI units are:

second | metre | kilogram | ampere | mole | candela | kelvin

Europe's National Measurement Institutes working together

The majority of European countries have a National Measurement Institute (NMI) that ensures national measurement standards are consistent and comparable to international standards. They also investigate new and improved ways to measure, in response to the changing demands of the world. It makes sense for these NMIs to collaborate with one another, and the European Association of National Metrology Institutes (EURAMET) is the body that coordinates collaborative activities in Europe.

EURAMET has implemented the European Metrology Research Programme (EMRP), a project programme organised by 22 NMIs and supported by the European Union, which will have a value of over 400 M€. The EMRP facilitates the formation of joint research projects between different NMIs and other organisations, including businesses, industry and universities. This accelerates innovation in areas where shared resources and decision-making processes are desirable because of economic factors and the distribution of expertise across countries or industrial sectors.

EURAMET wants to involve European industry and universities at all stages of the programme, from proposing Potential Research Topics to hosting researchers funded by grants to accelerate the adoption of the outputs of the projects.

Full details can be found at: **www.euramet.org**

Fixing the kilogram

Fixing the Planck and Avogadro constants

The mass of the international prototype of the kilogram, which is 1 kg by definition, is drifting with respect to the mass of its official copies over time.

In order to redefine the kilogram in terms of fundamental physical constants, there needs to be international agreement on the Planck constant and on the Avogadro constant. Two experiments have so far achieved accuracies close to the requirements: a watt-balance experiment linking mechanical and electrical power, at the National Institute of Standards and Technology (NIST) in the USA, and a silicon sphere experiment carried out by the International Avogadro Coordination (IAC).

However, there is a discrepancy between the values measured in these two experiments, which indicates error in at least one of them. This project aims to understand what this error is and to remedy it by delivering a European watt-balance determination of the Planck constant while also refining measurements and repeating the Avogadro determination. This will lead to lower uncertainties and it is a step towards the redefinition of the SI unit of mass.

Project SIB03
Realisation of the awaited definition of the kilogram – resolving the discrepancies

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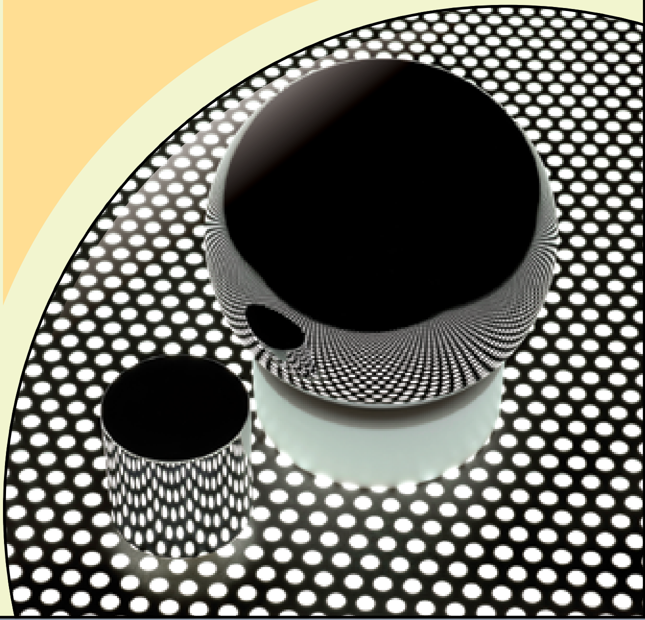

Trapped ion optical clocks

Improving the precision of optical clocks

Atomic clocks form the basis of timekeeping and are used in navigation and communications. The most advanced optical clocks now exceed the best clocks based on the current definition of the second in terms of reproducibility. The SI unit of time also plays a role in defining other units such as the metre and the ampere.

This project will produce a selection of optical clocks with the potential to become primary standards and make improvements to key components within the clocks such as ion traps and lasers. The clocks use laser-cooled trapped ions and trials of aluminium, strontium and ytterbium ions will identify the best candidates with regards to performance and complexity.

The goal of the project is to comprehensively evaluate the performance of optical clocks as well as to provide a set of absolute frequency measurements and a set of optical frequency ratio measurements, to be used as input to a redefinition of the second.

Project SIB04
High-accuracy optical clocks with trapped ions

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Next generation of mass standards

Disseminating the new kilogram

The SI unit of mass - the kilogram - is the last of the seven base measurement units defined in terms of a material artefact However, progress is being made towards a redefinition in terms of the Planck constant, realised via the watt balance and silicon sphere Avogadro experiments.

The current definition of the kilogram is realised by the international prototype of the kilogram in air, but the new definition will be under vacuum conditions. This means that a link between the mass of the kilogram in air and its mass in vacuum must be established.

This project will produce new mass standards to enable traceability between the existing mass scale and the new experiments. This will enable the implementation and dissemination of the new kilogram and ultimately lead to a redefinition of the unit of mass.

Project SIB05
Developing a practical means of disseminating the redefined kilogram

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Better measurements for modern radiotherapy

Linking the physical properties of radiation with biological impact

Radiotherapy treatments work by damaging the DNA of cancerous cells, leading to cell death. New treatments such as ion and proton beam therapy are more effective than traditional treatments. However, current techniques are not able to accurately measure their dosage.

This project will develop measurements and simulations to determine how the charged particles from radiotherapy interact as they pass through human tissue. This is known as the particle track structure and it depends on properties like the velocity and charge of the particles, as well as on characteristics of the target cells in the patient. Essentially, the project will compare the physical properties of the radiation itself with its impact on cancer cells.

The results will support an advance in ionising radiation metrology that will directly impact the treatment and the quality of life of those affected by cancer.

Project SIB06
Biologically weighted quantities in radiotherapy

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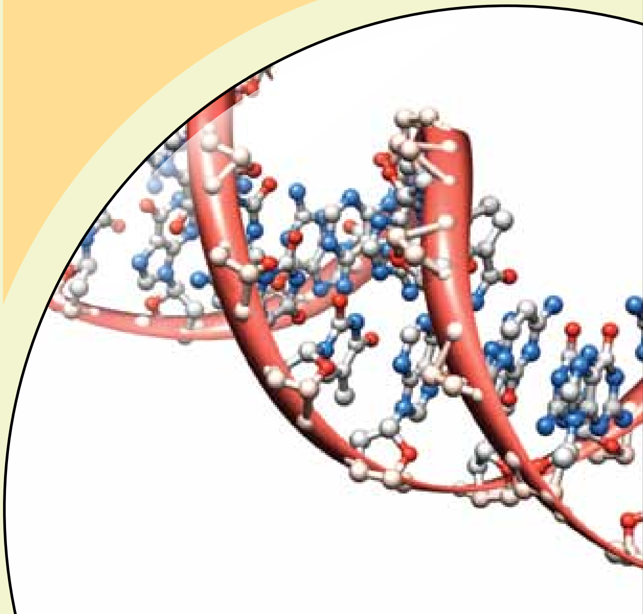

The new amp

Technologies for a new definition of the ampere

Electric current is the flow of electrons, each of which carries an identical charge. This charge is known as the elementary charge and is a fundamental constant of nature. The SI unit of electric current - the ampere - can therefore be defined in terms of a fixed value for the elementary charge.

To realise a new definition of the ampere we need to control the number of electrons that flow over time. This project will develop state-of-the-art Single Electron Transport (SET) devices – known as SET pumps - which generate electric current by moving only one electron at a time. The project will combine these SET pumps with ultrasensitive single electron detectors to create highly-accurate quantum current sources for use as standards.

The main impact of this project will be in fundamental electrical metrology but it could also result in faster electronic devices and in improved measurement capabilities in the semiconductor industry, in radiation dosimetry and in environmental monitoring.

Project SIB07
Quantum ampere:
Realisation of the new SI ampere

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Traceable measurements under one nanometre

Improving length and displacement measurements at the nanoscale

Although an error of less than one nanometre (or one billionth of a metre) may seem small enough to be inconsequential, there are already many important applications in metrology and industry that require uncertainties at this level.

Such high accuracy measurements are usually made with a device called an optical interferometer, which uses the relationship between the wavelength, frequency and speed of light to calculate a length. Capacitive sensors, in which the distance between two electrodes is calculated from the permittivity of the medium between them and the capacitance, or ability to hold charge, can also be used. Although these devices rely heavily on calibration to remain accurate over time.

This project aims to improve the traceability of high accuracy measurement devices used in National Metrology Institutes, nanomedicine, high-tech industries such as the semiconductor and nanopositioning industries, and the space industry, where calibrations need to be valid for the lifetime of the instrument.

Project SIB08
Traceability of sub-nm
length measurements

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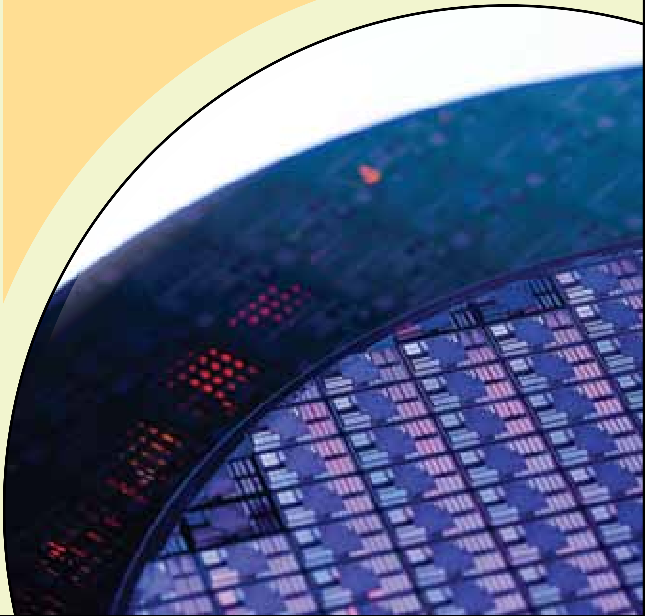

Improving chemical analysis

Pure chemical standards for measurements

There is currently a lack of primary standards for some chemical analysis. These standards are important for comparing chemical measurement results and are needed to fully implement EU directives such as the '*In Vitro* Diagnostic Medical Devices Directive' and the 'EU Water Framework Directive'.

This project will develop methods to realise standards for challenging elements frequently used in chemical analysis, including magnesium, zinc and molybdenum (used in steel alloys/nuclear medicine), and it will produce the standards for these elements in the process.

The project will also develop procedures for purity analysis, focusing on the detection of non-metal impurities such as hydrogen, and on the measurement of isotopic composition within samples. This will improve the comparability of measurement results, particularly when comparing a measurement result to the legal limit for that substance.

Project SIB09
Primary standards for challenging elements

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Fixing discrepancies in the temperature scale

Reducing uncertainties in temperature measurements

Temperature is one of the most frequently measured physical quantities in science and industry, with over two thirds of industrial processes monitored and controlled by temperature measurements. The International Temperature Scale of 1990 (ITS-90) is currently used throughout the world to calibrate temperature measurement equipment. The scale consists of a number of fixed points defined by the known melting/freezing points of certain chemical elements (and water).

After the redefinition of the kelvin in terms of the Boltzmann constant this scale will continue to be used, however it has limitations and these need addressing.

This project will resolve discrepancies in the realisation of the fixed points which will in turn lead to a reduction of the uncertainty associated with them. This will result in simpler and cheaper primary thermometers, new robust high performance sensors and reduced uncertainties in temperature measurement.

Project SIB10
Novel techniques for traceable temperature dissemination

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