Bureau International des Poids et Mesures

Task Group for the Promotion of the SI

Speaking notes

The SI is a worldwide endeavour and approach

The SI is the universal language of measurement.

The proposed changes to the SI will be the result of worldwide agreement at the General Conference on Weights and Measures (CGPM) in 2018. Metrology is a field where the states and economies of the world work together.

Speaking notes:

What is the SI?

The International System of Units (SI) is the modern form of the metric system, and forms the basis of the agreement for the system of measurement which is used throughout the world. It is presented as seven coherent system of units – the kilogram, the metre, the second, the ampere, the kelvin, the mole and the candela. These units underpin many other measurements.

How we realise these units is either through a physical artefact (the Kilogram) or a scientific experiment. The SI has been periodically updated to take account of advances in science and the need for measurements in new domains. This proposed revision will decide that the SI would be based on the fixed numerical values of a set of seven defining constants from which the definitions of the seven base units of the SI would be deduced.

Illustration: The SI units are the foundations of measurement throughout the world. As with a house, if the foundations are unreliable the structure will fail. If the foundations of measurement are not properly established all the other things that rely upon them will adversely impacted. As measurement is all pervasive across science, technology and our everyday life, these foundations are fundamental and give you confidence to build upon them.

Illustration: We completely depend on the reliability of the weights displayed on food in shops – we don't take our own scales to check if they're honest. These weights are regulated, but ultimately they are trustworthy because of the underpinning foundation of the SI unit of mass.

Key message – *In everyday life, most people take the ability to measure reliably for granted.*

Who is involved in agreeing the SI?

The General Conference on Weights and Measures (Conférence Générale des Poids et Mesures or CGPM) is a meeting, every four to six years, of delegates from all member states. It receives, discusses and then endorses new developments in the SI on the advice of the CIPM.

The International Committee for Weights and Measures (Comité International des Poids et Mesures or CIPM) is a committee that meets annually and is made up of eighteen individuals representing different countries of high scientific standing, nominated by the CGPM. It advises on administrative and technical matters relating to the SI.

The International Bureau of Weights and Measures (Bureau International des Poids et Mesures or BIPM) is an international metrology centre at Sèvres in France that provides metrology services for the CGPM member states, advises the CIPM, houses the secretariat for these organisations, brokers coordination between National or Regional Metrology Institutes and hosts their formal meetings. It has custody of the International prototype kilogram, and originally its prime metrological purpose was a periodic recalibration of national prototype metres and kilograms against the international prototypes which define the SI. Today it acts as the hub of the global metrology system.

Key message - *A truly international endeavour with 58 members and 41 associate countries represented through various committees. Working together for the common good ensures that measurements are mutually comparable and consistent.*

Using the rules of nature to create the rules of measurement

The use of the unchanging rules of nature enable you to create unchanging rules of measurement. The use of constants of nature enables you to link from the smallest to the largest measurement quantities.

It will tie measurements at the atomic (and quantum) scales to those at the macroscopic level. This is the appeal for the changes.

Speaking notes:

What is wrong with the old system?

We have two challenges with the old system:

1. The reliance upon the remaining physical artefact - the International Prototype Kilogram (IPK)

Many measures began life as a physical artefact, such as the metre bar, but the IPK is the only remaining such artefact that defines a unit.

Physical artefacts can change, be damaged or even destroyed. In addition, it is an arduous task to achieve a reliable traceability chain from one point in the world. By its very nature, the mass of the IPK is not stable and it is suspected to have been subject to unknown changes since 1889, yet it remains the defined standard. Currently, national prototype kilograms throughout the world have to travel periodically to BIPM in France, the custodian of the IPK, to compare their weight. Just the act of travelling to and from France introduces risks to each national artefact.

Key message – *Removing the last physical artefact (the IPK) from the SI system and replacing it with something fundamental and stable has been the aspiration of the CGPM for over 200 years and is now about to be implemented.*

2. The combination of both the definition and the realisation of the SI units

A measure has two important aspects – the definition of the unit (e.g. a centimetre) and the method you use to measure it (e.g. a ruler). If you can divorce these two concepts, it enables the definition to remain stable and the process of realising it to be improved over time without a major revision to the agreed system.

Basing the definitions on fundamental constants is key to this. Because the constants do not change their numerical values our definitions remain the same. Many decades of intense research has been undertaken and universally agreed that these constants have the level of stability that makes them a fundament constant. But this does represent the extent of our knowledge of nature at this point in time.

It is proposed that the redefined SI system of units will be based on the following fundamental constants:

- the unperturbed ground state hyperfine transition frequency of the caesium-133 atom ΔvCs is 9 192 631 770 hertz
- the speed of light in vacuum c is exactly 299 792 458 metres per second
- the Planck constant h is exactly 6.626 070 15 x 10^{-34} joule seconds
- the elementary charge e is exactly 1.602 176 634 x 10^{-19} coulombs
- the Boltzmann constant k is exactly 1.380 649 x 10^{-23} joules per kelvin
- the Avogadro constant NA is exactly 6.022 140 76 x 10^{23} reciprocal moles
- the luminous efficacy K_{cd} of monochromatic radiation of frequency 540 x 1012 Hz is exactly 683 lumens per watt

The Planck constant is currently measured with reference to the SI units, but will be agreed as a fixed numerical value as a result of the work on the Kibble balance and the Avogadro project. It will be defined as exactly 6.626 070 15 x 10^{-34} joule seconds, which in turn defines the unit Js.

Illustration: The new definition of the ampere will be based on the elementary charge of the electron, which we believe to be a fundamental constant of nature. The realisation of the unit involves counting the number of electrons, each with exactly the same elementary charge, flowing through a wire. So as you improve your ability to count electrons you can increase the accuracy of realising your standards, without the definition of the standard changing.

Key message – *We have a set of fundamental constants to base the SI units on. These remain unchanging but the process of realisation can change and improve as technology allows.*

What are the aims of the redefinition of SI?

The aim of the redefined SI is to future-proof the system.

If we consider the SI units to be the foundations of every quantity we measure, we wish to ensure these foundations do not crack in the future. Cracks appear when you put unforeseen strain upon a system. The strain on our measurement system comes from demand for greater accuracy or requirements for measurements at extremes that were not considered when the unit was originally defined. The redefined SI has been preceded by many decades of intense research to establish experiments which test the relations between fundamental physics and the measurement system.

Illustration: Think of bridges coping with modern traffic loads that could not have been predicted when they were built.

Illustration: Currently you weigh something heavier than a kilogram, you add more and more kilograms together, so there is a reproducibility that allows you to scale up. At the other end of the scale, weighing smaller amounts than a single kilogram requires you to carve up the kilogram. As you get smaller and smaller divisions, it becomes harder to do this accurately. Imagine cutting a chocolate bar up into 20 pieces as opposed to 2000 pieces – then you can see the issue. But there are industries that are interested in *measuring at the microgram and even nanogram levels, such as the pharmaceutical world, where ensuring the exact amount of a drug within a tablet is vital. Our aim is to ensure the same level of accuracy for measurements across the entire scale.*

Illustration: The same problem of making measurements at values very different from the standard applies even more strongly to temperature measurement. The current definition is based upon a defined value of the triple point of water i.e. the temperature at which ice, liquid water and water vapour can co-exist (defined as 273.16K). When measurements are made at temperatures very different from the water triple point (think of processing metals at greater than 1500 °C), it becomes increasingly difficult to work out precisely how much hotter this is than the triple point of water. To establish reliable temperature measurements world-wide, we currently use a 'recipe book' of different approaches to make the comparison to the triple point of water. But after the redefinition, temperature measurements will no longer require a link to the water triple point and users will be able to use whichever fundamental method is appropriate to their requirements. This will not make much difference at the moment, but it opens the doors to many possible technological improvements.

Key message – *As the custodians of the foundations of measurement, we need to ensure our measurements are future-proof, ensuring confidence for decades to come.*

The redefinition of the SI will provide a springboard for future innovation

The changes will mark an important step forward. Scientific advances now offer the possibility to do better and move forward while maintaining continuity for practical users.

Speaking notes:

What will future-proofing enable?

It is sometimes hard to predict what future-proofing our measurement system will enable, but we like to think that if we provide the ability to measure more accurately it will enable others to build upon this.

Looking back 100 years, our experiments and technology would look very dated and we can never be certain what the future will hold.

Illustration: When the atomic clock was developed to measure time more accurately, the field of computing was in its infancy and the digital revolution had not even been thought of. Yet, highly accurate timing is fundamental to this entire industry; without it the internet, mobile phones and other technologies would fail. At this point in time, the accuracy of GPS is limited by our ability to disseminate the standard in it of time and to thus improve GPS further we need to working together as a worldwide community.

Illustration: The measurement of accurate temperature will certainly support the ability to identify and reliably measure very small changes in temperature over large periods of time with greater accuracy. The most pressing need for this is in monitoring and predicting climate change.

Illustration: Improving the ability to measure mass at very small levels will support the pharmaceutical industry, which is constantly looking at how to make medication dosages even more accurate, especially with the increase in bespoke medication.

Key message – *Future-proofing enables anyone to make measurements with confidence and know that they will remain stable for decades to come.*

What is the impact of the changes?

The immediate impact of the changes will be minimal and this is important. You do not want to introduce fundamental step changes in the measurement system. In fact, apart from the ampere, there will be little immediate impact to the units. But the changes will guarantee the future ability of the SI units to evolve and lay the foundations for future improvements without the definitions having to change.

The impact on electrical measurements will be immediate. The realisation of the ampere will make use of the new fixed elementary charge, and will result in a change at the level of 1 part in 10^{7}. However this will only affect calibration laboratories working at the highest levels of accuracy, not most practical uses of the ampere.

Key message – *Changing the SI is not about revolution, it is about long-term evolution.*