Metrology and the International Quality Infrastructure

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29th November 2017

Bureau
International des
Poids et
Mesures

Outline

01 - The Meter Convention and the BIPM

02 –Metrology and the International Quality Infrastructure

03 – Towards a re-definition of the SI

Bureau International des Poids et Mesures

Why was the Metric system of so much interest?

The Metric System was first introduced after the French Revolution:

to allow fair trade by weight and length.

The definitions were:

- **The metre** = one ten millionth of the meridian of the earth (through Paris).
- **The kilogram**= the mass of $1 dm^3$ of water (at its temperature of maximum density).

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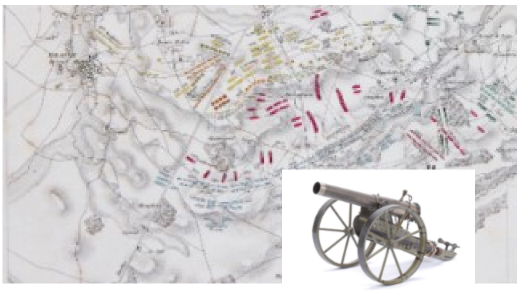
Why was the Metric system of so much interest?



And
there were new demands for more accurate measurements.

Provost, Exposition universelle de 1855, vue de la grande nef du Palais de l'Industrie, 1855, Lithographie en couleurs, musée d'Orsay

DOCUMENTS DIPLOMATIQUES

DE

LA CONFÉRENCE DU MÈTRE.

PARIS.

IMPRIMERIE NATIONALE.

1875.

20 May 1875

The Metre Convention was signed in Paris

by 17 nations

The BIPM – an international organisation

“the intergovernmental organization through which Member States act together on matters related to measurement science and measurement standards”

Established in 1875 when 17 States signed the Metre Convention.

CGPM – Conférence Générale des Poids et Mesures

Official representatives of Member States.

CIPM – Comité International des Poids et Mesures

Eighteen individuals of different nationalities elected by the CGPM.

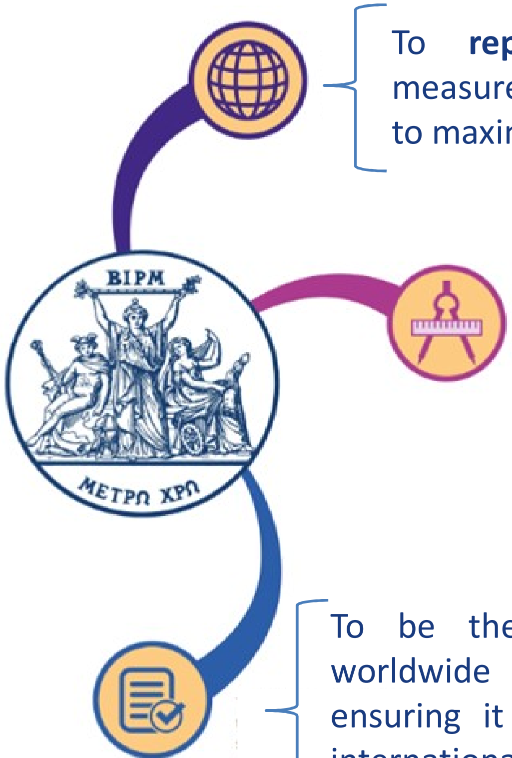
BIPM – Bureau International des Poids and Mesures

- *International coordination and liaison*
- *Technical coordination – laboratories*
- *Capacity building*

Consultative Committees (CCs)

CCAUV – Acoustics, US & Vibration
CCEM – Electricity & Magnetism
CCL – Length
CCM – Mass and related
CCPR – Photometry & Radiometry
CCQM – Amount of substance
CCRI – Ionizing Radiation
CCT – Thermometry
CCTF – Time & Frequency
CCU - Units

The objectives of the BIPM



To **represent** the worldwide measurement community aiming to maximise its uptake and impact

To be a **centre for scientific and technical** collaboration between Member States providing capabilities for international measurement comparisons on a shared-cost basis.

To be the **coordinator** of the worldwide measurement system ensuring it gives comparable and internationally-accepted measurement results

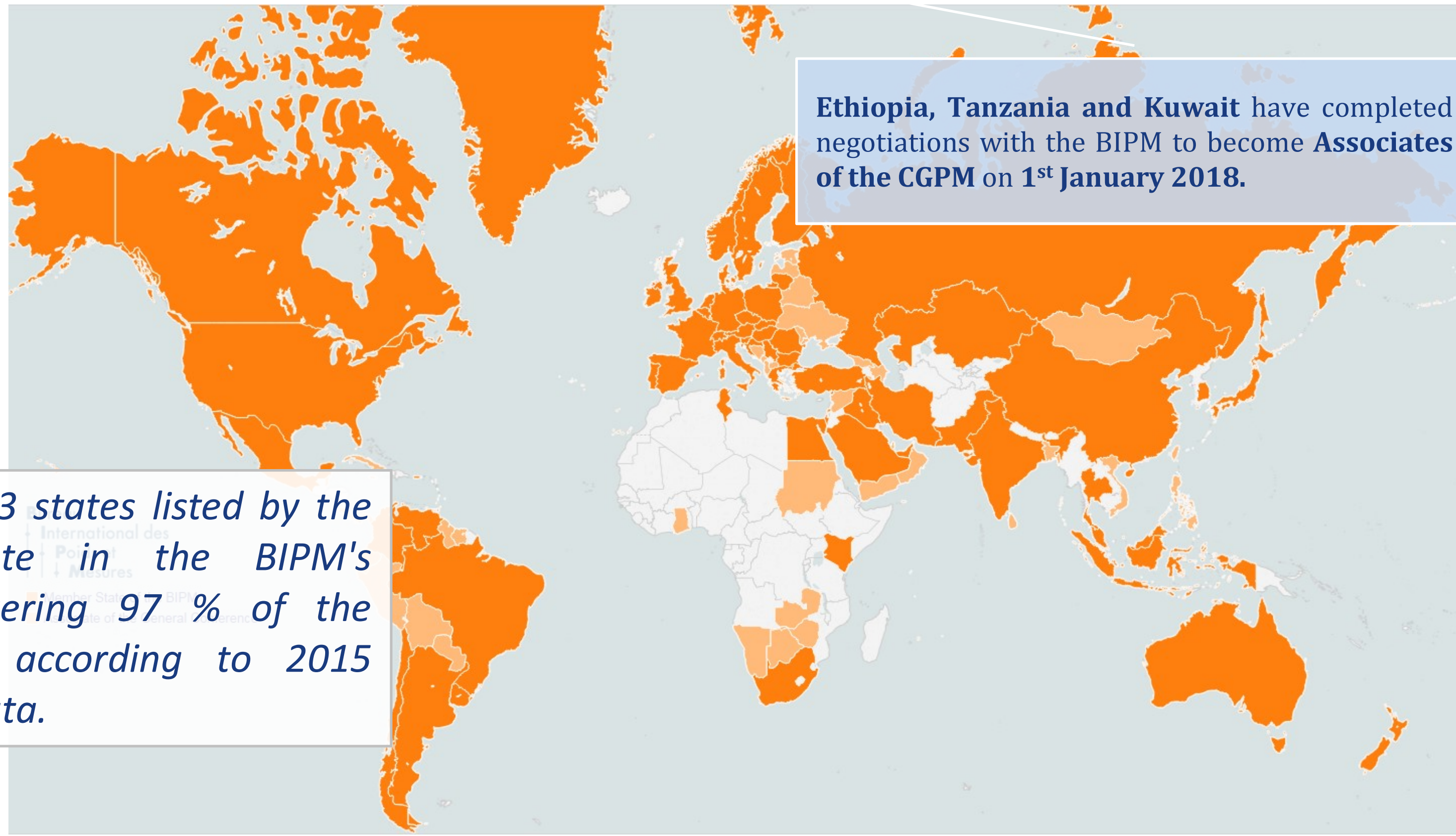
Fulfilling our mission and objectives is underpinned by our work in:

- ***capacity building**, which aims to achieve a global balance between the metrology capabilities in Member States.*
- ***knowledge transfer,** which ensures that our work has the greatest impact.*

Member States and Associates

As of today, there are:

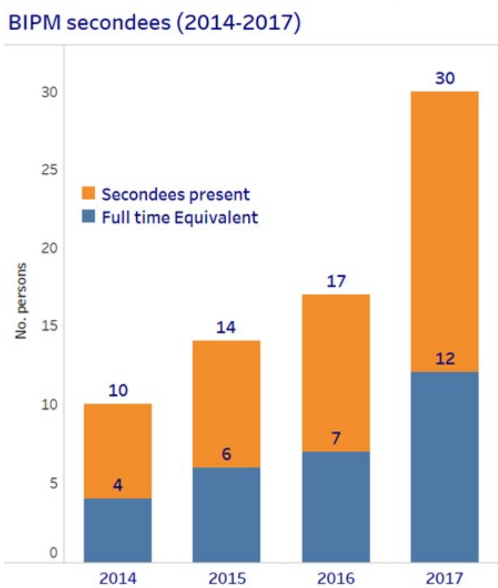
- **58 Member States**
- **41 Associates**
  (States and Economies) of the CGPM



Ethiopia, Tanzania and Kuwait have completed negotiations with the BIPM to become **Associates of the CGPM** on **1st January 2018.**

107 of the 193 states listed by the UN participate in the BIPM's activities, covering 97 % of the world's GDP according to 2015 World Bank data.

The BIPM Staff



We have 71 staff from 21 countries

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Standardization and Accreditation
bring measurements to industry

Metrology provides

Knowledge Transfer

Industry Needs

Measurement technologies

International standards
*a **key exploitation and dissemination** vehicle for best practice*

Validate new ideas

Measurement methods

Generate, optimise and assure confidence in the technical data innovators need
(calibrations, CRMs, advice…)

Improve process efficiency

Reduce waste/downtime

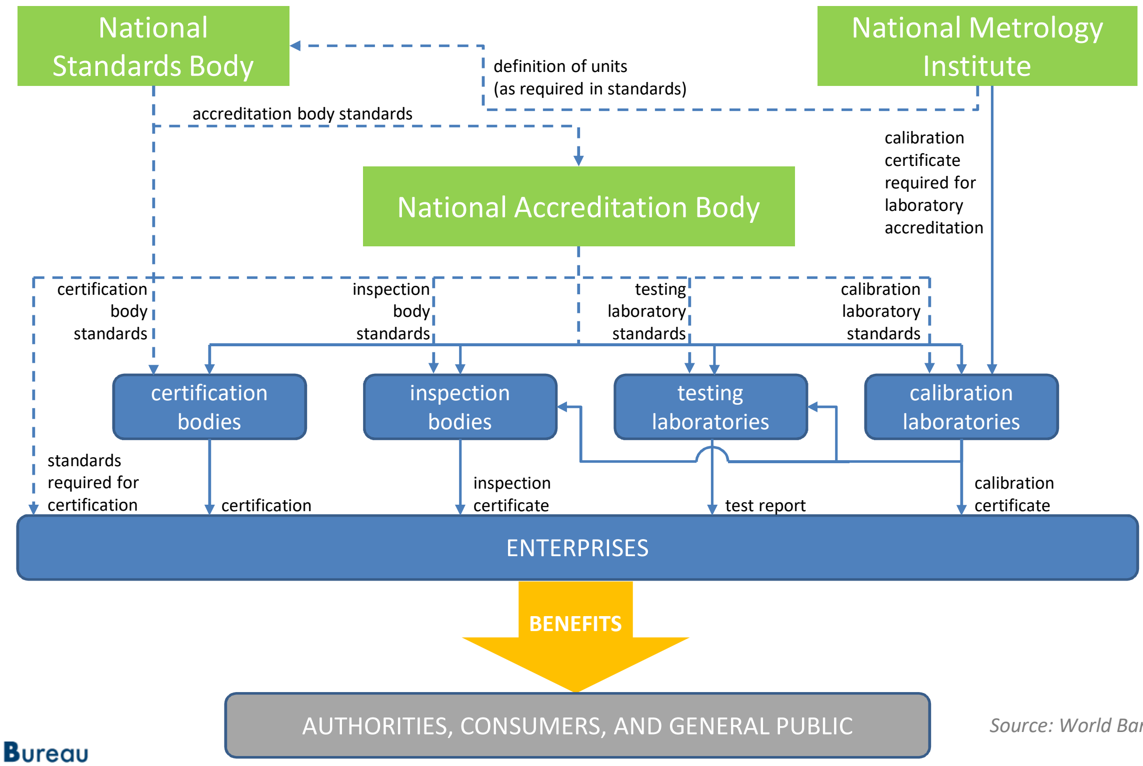
Nationally and internationally aligned standards

Accreditation
*an internationally recognised **conformity assessment** mechanism that ensures metrological traceability*

Increase reliability

Meet standards/regulation

Global Quality Infrastructure (QI)



Source: World Bank

- Enhanced product quality and compatibility
- Enhanced safety and health
- Decreased environmental impact
- Increased trade opportunities
- Facilitating innovations to the market place

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Global Quality Infrastructure (QI)

Definition adopted in June 2017
by DCMAS Network (BIPM IAF, IEC, ILAC, ISO, ITC, ITU, OIML, UNECE and UNIDO) + the World Bank.

"The system comprising

the organizations (public and private)
together with the policies, relevant legal and regulatory framework, and practices needed
to support and enhance the quality, safety and environmental soundness of goods, services and processes.

The quality infrastructure is required for the effective operation of domestic markets, and its international recognition is important to enable access to foreign markets. It is a critical element in promoting and sustaining economic development, as well as environmental and social wellbeing.

It relies on

- ***metrology***
- ***standardization***
- ***accreditation***
- ***conformity assessment, and***
- ***market surveillance"*** *(in regulated areas)*

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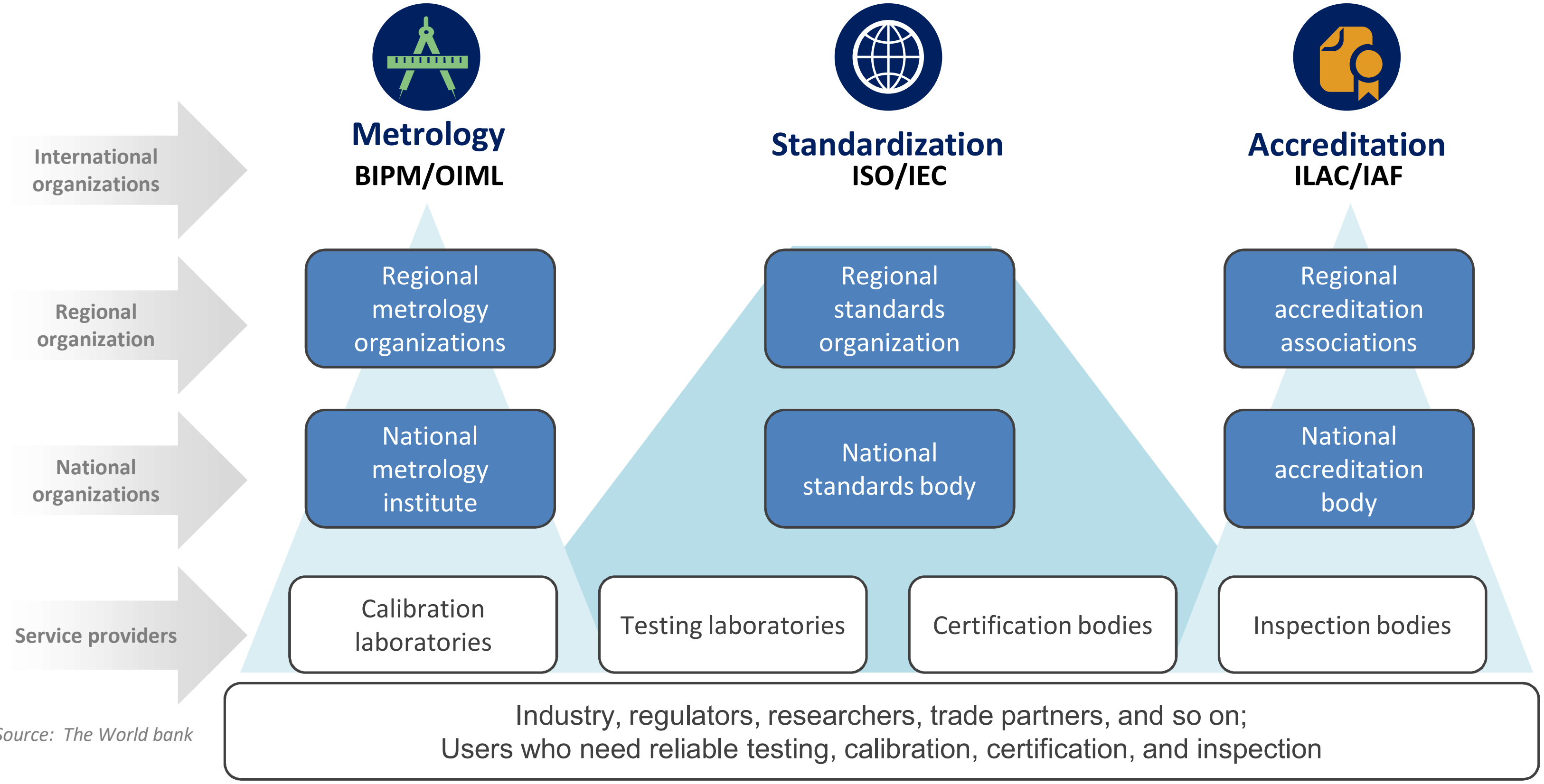
Key players at international, regional and national level



Source: The World bank

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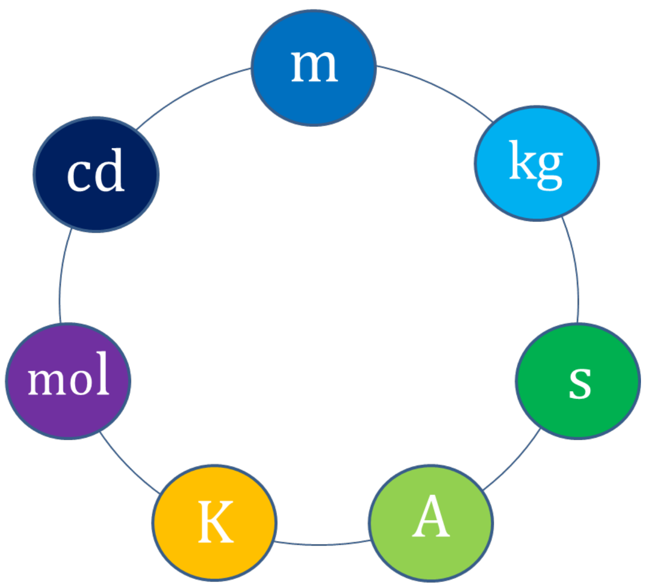
The International System of Units (SI)



Système International d'Unités (SI)

The name adopted by the 11th CGPM in 1960
for the system with 6 base units.

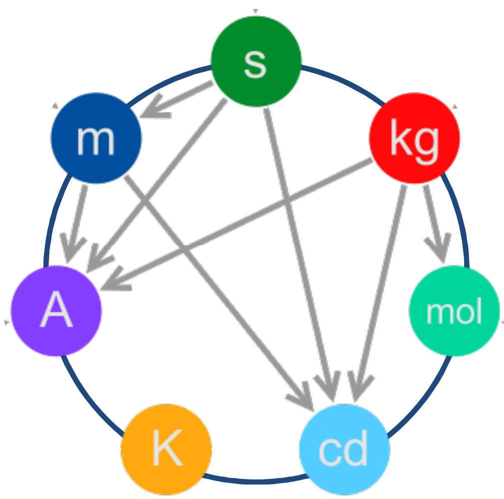
kilogram, second, metre,
ampere, kelvin and candela.

Five important changes since 1960:

1967	the second was redefined – the atomic second
1972	the mole was introduced – to provide a unit for chemistry
1983	the meter was redefined – the first fundamental constant.
1990	conventions for the volt and the ohm adopted.
1990	the International Temperature Scale (ITS90) was adopted.

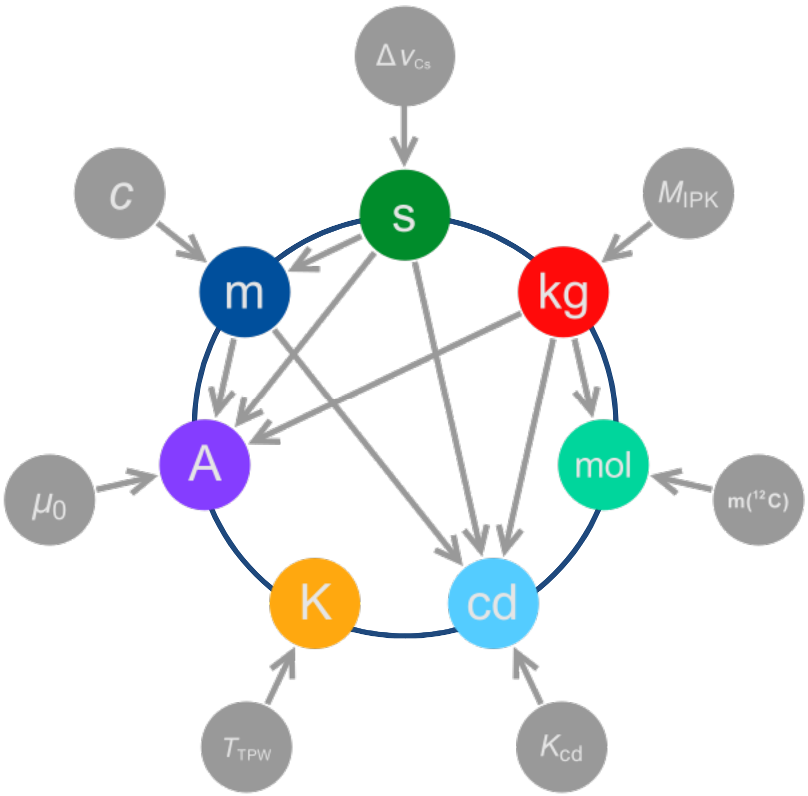
and many smaller changes too, except to the kg!!

The re-definition in diagrams



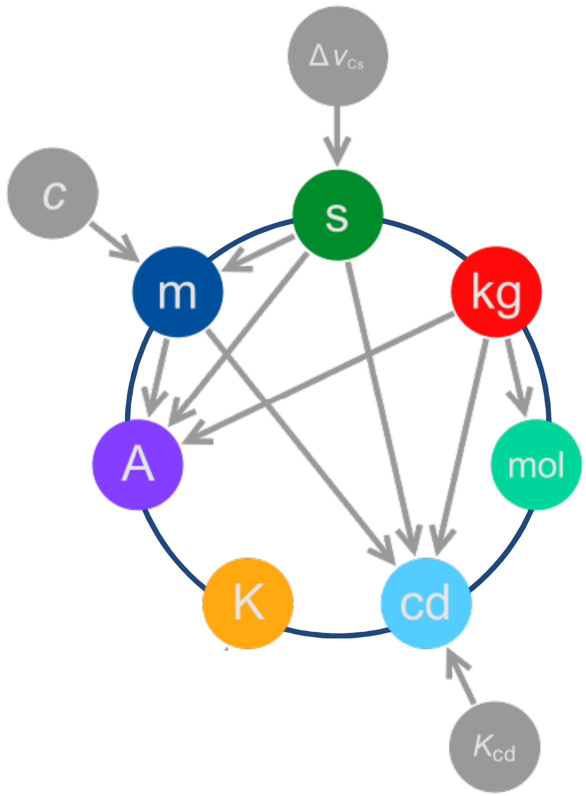
Seven base units –that are linked together.

The re-definition in diagrams



We propose to change the definitions of four of them.

The re-definition in diagrams



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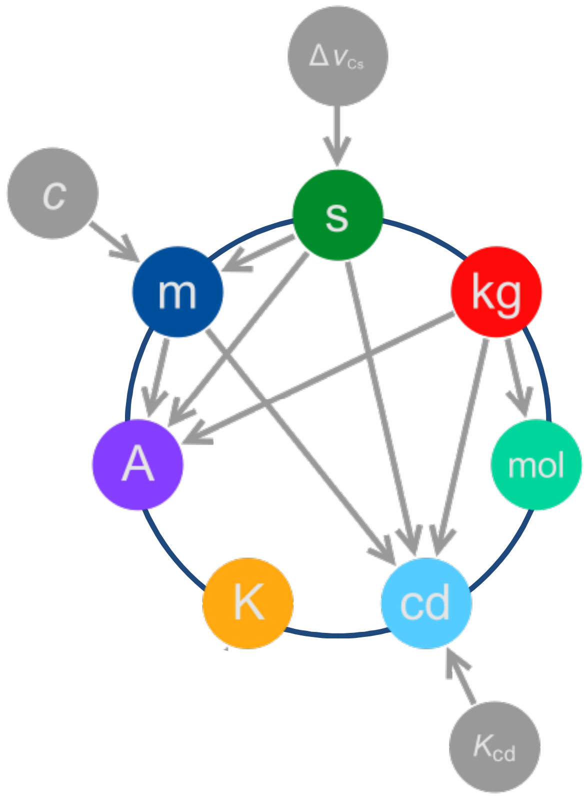
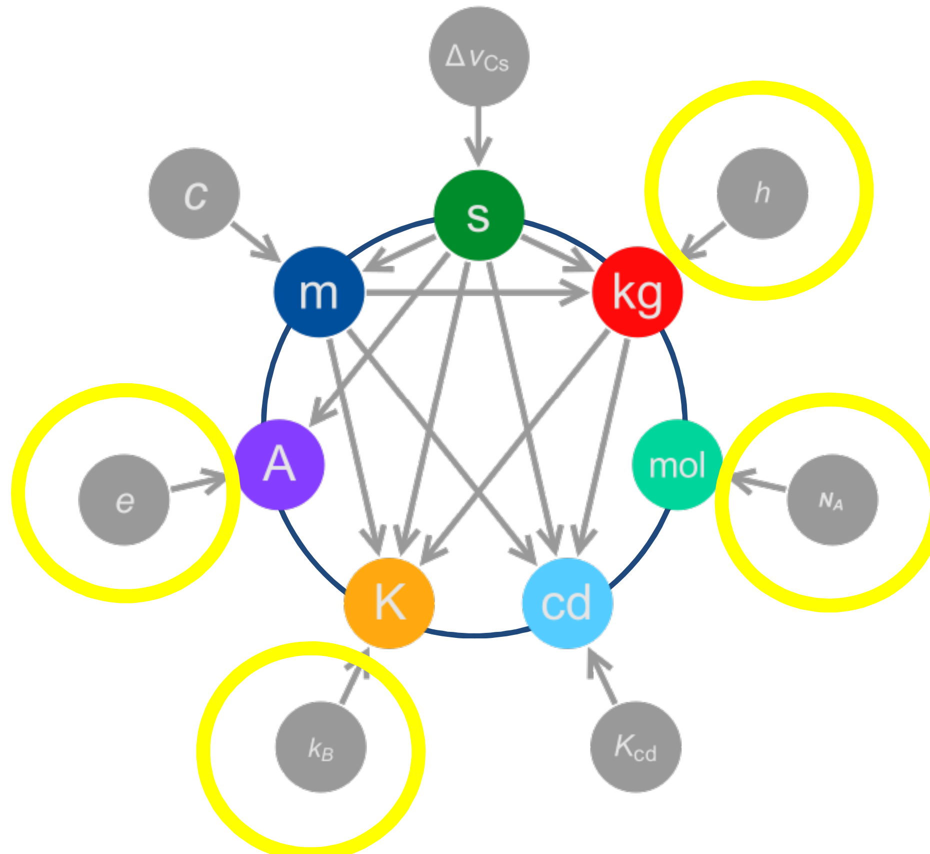


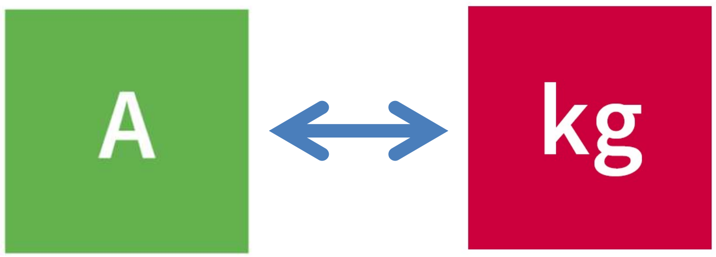


Introducing 4 new definitions.

A re-definition of the SI is being proposed for 2018

What will change?

- the ampere,
- the kilogram,
- the kelvin, and
- the mole.



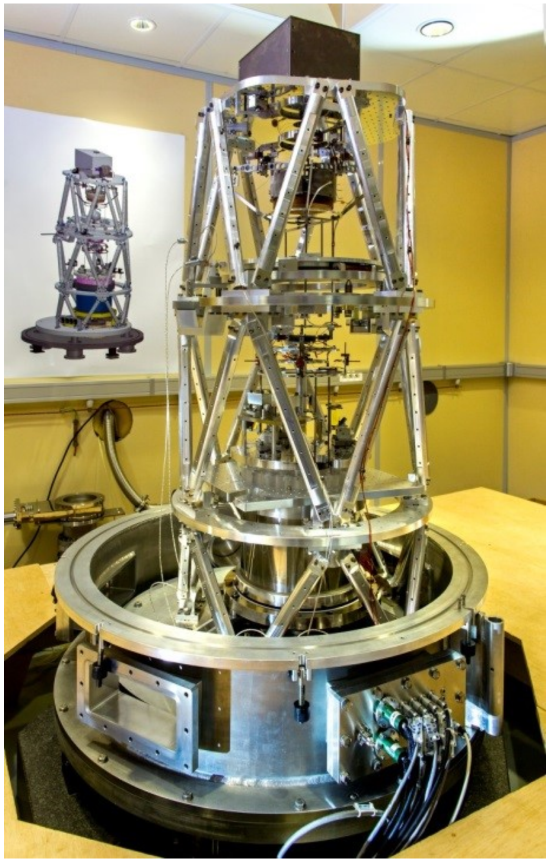
Why make the change?

- What will the consequences be?
- How should we present the changes?

A new way to link electrical units to mechanical units

- An experiment that links electrical power to mechanical power.
- The « moving coil watt balance »
- Now called the Kibble Balance.

Bryan Kibble
(1938 - 2016)



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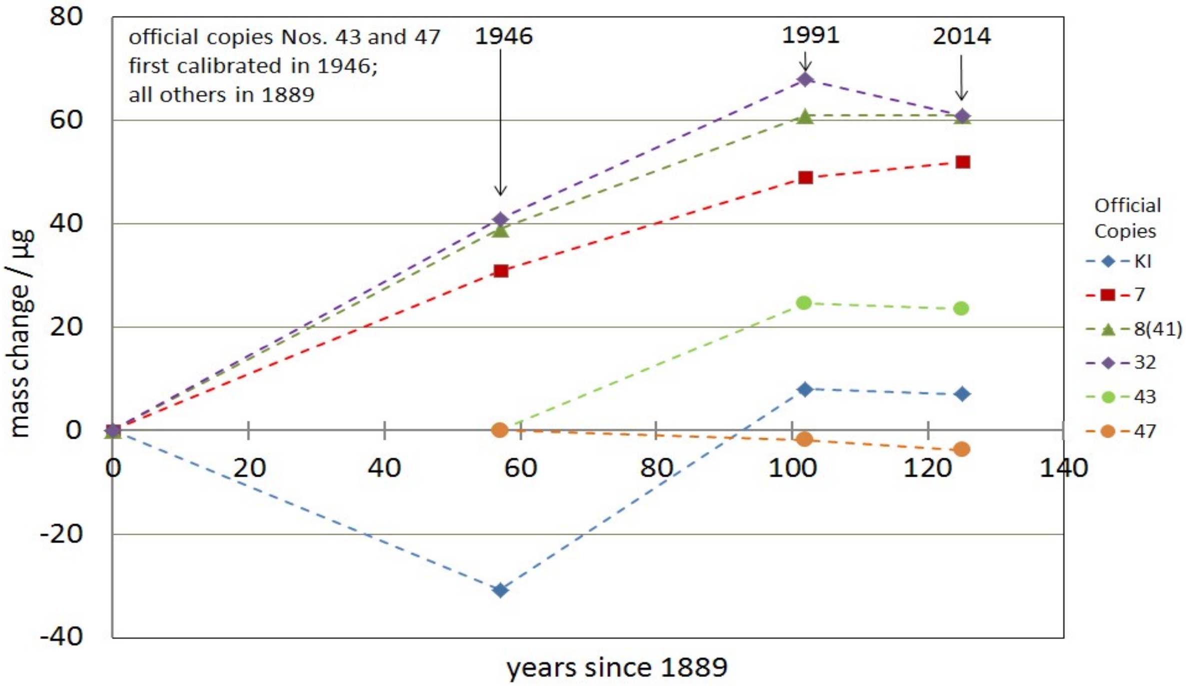
The definition of the kilogram in the SI

The kilogram is the unit of mass -
it is equal to the mass of the
international prototype of the kilogram.

- manufactured around 1880 and ratified in 1889
- represents the mass of 1 dm^3 of H_2O at its maximum density (4 °C)
- alloy of 90% Pt and 10% Ir
- cylindrical shape, $Ø = h \sim 39$ mm
- kept at the BIPM in ambient air

The kilogram is the last SI base unit defined by a material artefact.

Why make the change ? – the IPK



The IPK and the six official copies form a very consistent set of mass standards

average change wrt to IPK: -1 µg

standard deviation: 3 µg

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But

- We just discussed how the Kibble balance can set **mechanical = electrical power**

$$\text{Mechanical Power} = \text{Electrical Power}$$

But

- We just discussed how the Kibble balance can set **electrical = mechancial power**

$$m\,g\,v = \frac{h}{4} f_1 f_2$$

But

- We just discussed how the Kibble balance can set **electrical = mechancial power**

$$m\,g\,v = \frac{h}{4} f_1 f_2$$

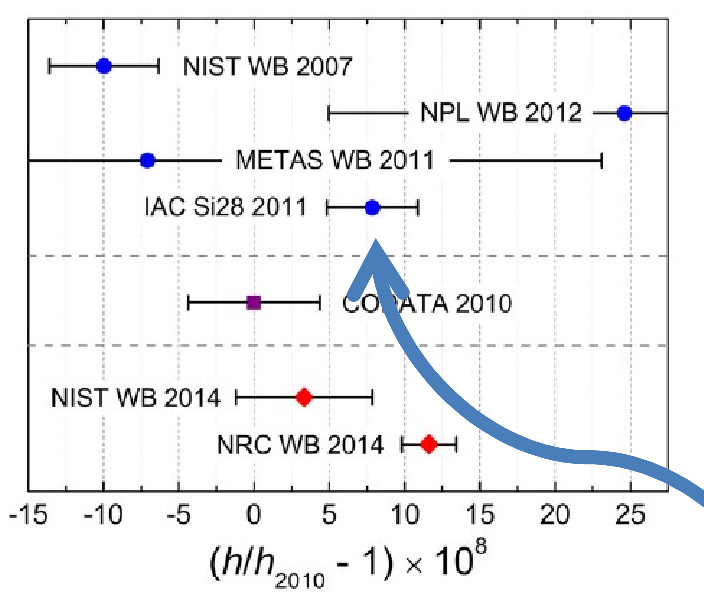
- If we can measure *h* with an uncertainty of some parts in 10^8.

- Then the Kibble Balance can define the kilogram to some part in 10^8 - if we fix the Planck Constant.

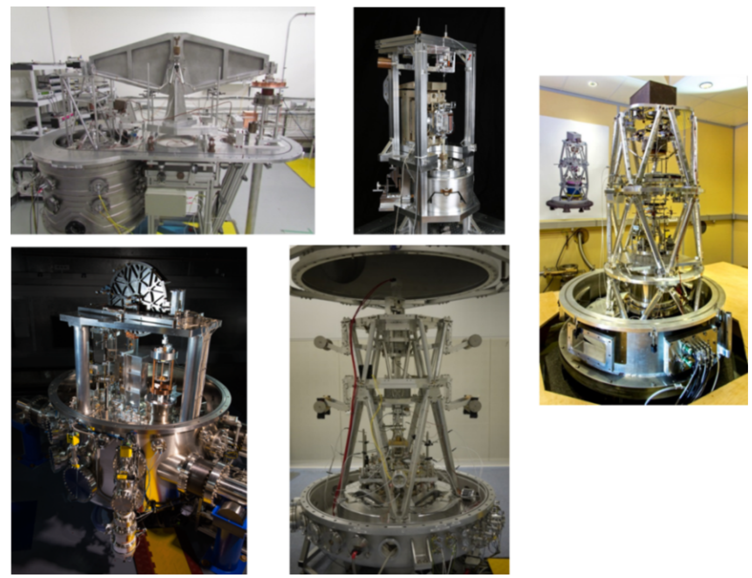
Why did'nt we agree to implement this many years ago?

It has not been easy to agree on the best value of the Planck constant

Metrologia **51** (2014) R21



Many Kibble balances have been commissioned to resolve the discrepancy – and hence to realise the kg.



Values for *h* are available from other methods, including one that can be used to realised the kg.

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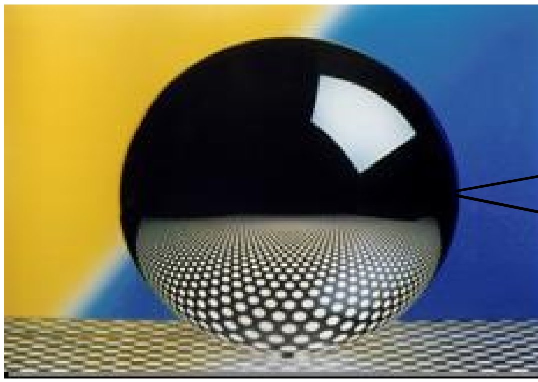
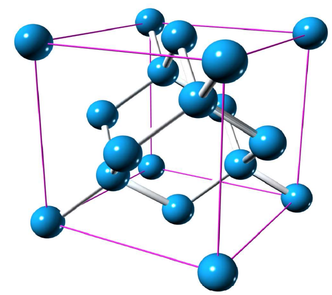
The X-ray crystal density (XRCD) method



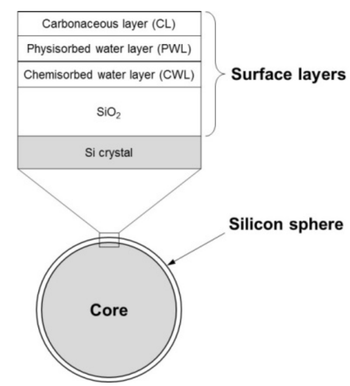
8 atoms per unit cell



$$M = N\,\overline{m}_{Si} = \frac{8\,V}{a_0^3}\,\overline{m}_{\mathrm{Si}} = \frac{8\,V}{a_0^3}\,\frac{\overline{M}}{N_{\mathrm{A}}}\ :$$

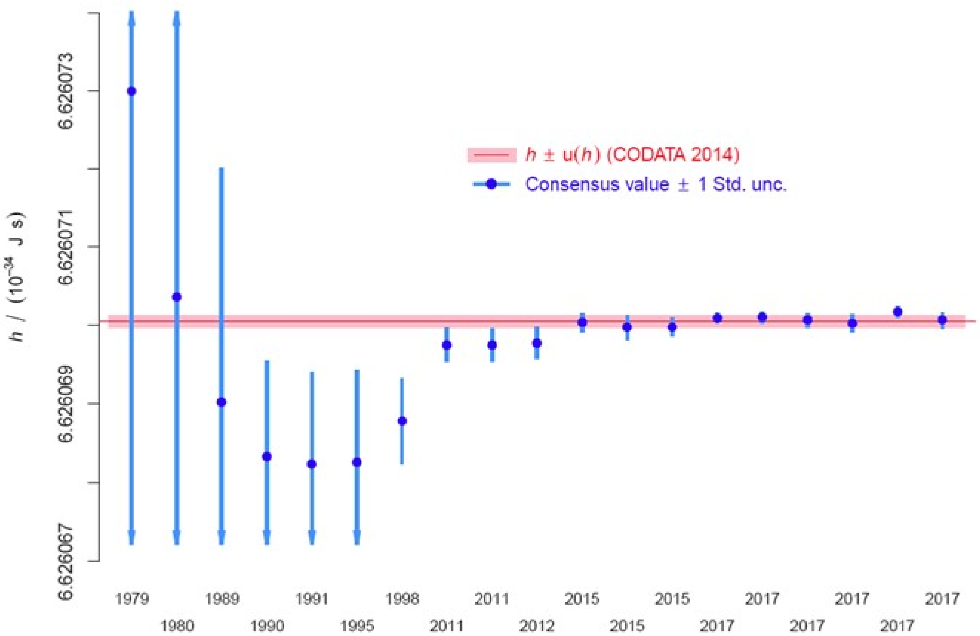
N_{A} can be converted to a measurement of h because of our knowledge of the Bohr atom.

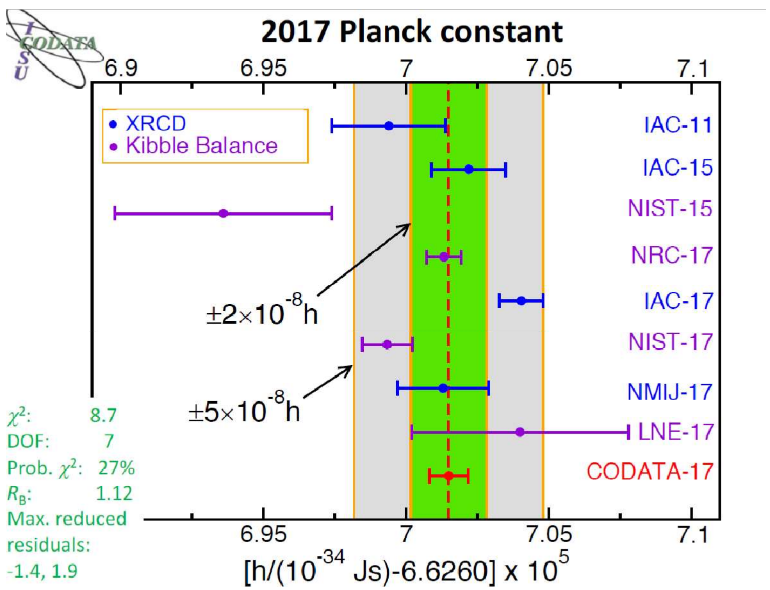
$$h.N_A = \frac{cA(e)_r M_u \alpha^2}{2R_\infty}$$



$$m_{\mathrm{sphere}} = m_{\mathrm{core}} + m_{\mathrm{SL}}$$

Progress with the measurement of the Planck constant





h $\quad 6.626\,070\,150(69) \times 10^{-34}$ J s $\quad 1.0 \times 10^{-8}$

Data from CODATA 2017

Writing the new definitions eg the ampere

"The ampere … is defined by taking the fixed numerical value of the elementary charge e to be 1.602 176 620 8 $\times 10^{-19}$ when expressed in the unit C, which is equal to A s, where the second is defined in terms of $\Delta\nu_{Cs}$.

How does this work in practice?

Since *h* is fixed by the definition of the kilogram and *e* by the definition of the ampere:

- **The quantum Hall effect defines an impedence in terms of h/e^2**
- **The Josephson effects defines a voltage in terms of $2e/h$**

How can we explain the new definitions?

- **The new definitions will “facilitate universality of access to the agreed basis for worldwide measurements”.**
  - This has been an ambition for the “metric system” that goes back more than 200 years. The 2018 definitions will make it possible for the first time.
- **The changes will underpin future requirements for increases in accuracy**
  - As science and technology advances, the demands for the accuracy of measurements will continue to increase accuracy. The 2018 definitions will provide for these needs for many years to come.

Summary

The new definitions use "the rules of nature to create the rules of measurement".

they will tie measurements at the atomic (and quantum) scales to those at the macroscopic level.

The new definitions will provide long-term stability

Realisation of units will be possible using new methods.

The challenge in the future will be to maintain comparability of "primary realisations"

- the same challenge that we have with (most) other measurement units.
- Coordination becomes an even greater challenge.

Summary

The true challenge is "**for all times for all people**"
The new definitions will provide one aspect of this
–there are many others

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Capacity Building & Knowledge Transfer

Thank you

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